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Vol. 222 — **SEPTEMBER, 1936** — **No. 3**

CONTENTS

Flight on Rotating Wings ..... W. LAURENCE LEPAGE 255

The Petoscope: A New Principle in Photo-Electric Applications . ALAN S. FITZGERALD 289

On the Anomalous Properties of Dielectrics ..... JACOB NEUFELD 327

Further Notes on Sampling Analysis, with Application to Coal
M. C. HOLMES AND RICHARD DOWNS 337

Residual Moisture in Cellulose Dielectrics ..... E. W. GREENFIELD 345

Civilization Since James Watt ..... JULIAN P. BOYD 359

Notes from the U. S. Bureau of Standards 365

The Franklin Institute Notes 375

Book Reviews 377

Publications Received 383

Current Topics 326, 344, 364, 374, 385

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INDEX TO ADVERTISERS

	PAGE
American Telephone and Telegraph Co. .....Third cover page	
Commercial Photo Engrav. Co. Fourth cover page	
Dreka Co.	ii
Electrical Testing Laboratories ..	ii
Fehr, Herbert C.	ii
Fidelity-Philadelphia Trust Co. ..	iii
FRANKLIN INSTITUTE, Awards of	v
FRANKLIN INSTITUTE, Endowments	viii
FRANKLIN INSTITUTE, Membership, Terms and Privileges ...	vi
FRANKLIN INSTITUTE, Membership, Terms and Privileges ...	vii
Girard Trust Co. ..Fourth cover page	
Glynn Kohler Printing Co.	ii
Kidder, Peabody & Co. Fourth cover page	
Lancaster Press, Inc. Second cover page	
Mann, Wm. & Co.	ii
Sadtler, Samuel P., and Son, Inc.	ii
Smith, Haseltine, & Co., Inc. Second cover page	

Journal
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Vol. 222 SEPTEMBER, 1936 No. 3

FLIGHT ON ROTATING WINGS.*

BY

W. LAURENCE LePAGE,

Day & Zimmermann, Inc., Philadelphia, Pa.

SOME LANDMARKS IN THE HISTORY OF FLIGHT ON ROTATING WINGS.

The original conception of the rotating wing flying machine appears to date back to the fifteenth century, when Leonardo da Vinci made strange-looking sketches in his notebook, sketches which portray without a doubt that he was thinking of a flying machine, the wings of which would turn. However, it was in 1784 that the French scientists *Launoy and Bienvenu* constructed the first helicopter which actually flew. It was a small model, a simple scientific toy, the motive power of which was supplied by the tension of a bow bent by the winding of its string about the shaft of the upper of two rotor systems made of feathers. It is recorded that the device functioned perfectly.

It is interesting to record that the airscrew was considered, during the nineteenth century, the simplest means of obtaining mechanical flight in heavier-than-air machines, and helicopters copied more or less directly from the models of Launoy and Bienvenu and of Sir George Cayley were conceived and to some extent realized.

* Presented at a meeting held Thursday, April 2, 1936.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

Maurice Léger.

In 1905, in the hall of the Oceanographic Museum in Monaco, Maurice Léger experimented with a helicopter having two concentric screws of about 20 feet diameter turning in opposite directions. The drive was by an electric motor which remained on the ground and drove the screws through a flexible shaft. The weight of the portion lifted, including the airscrews, frame and transmission, was 187

Launoy & Bienvenu model, 1784.

pounds. The machine rose under these conditions with an additional dead weight of 55 pounds, the screws turning at 40 r.p.m. and absorbing 6.1 horsepower. It is particularly interesting to note that this represents about 40 lb./hp. and a disc loading of .7 lb./sq. ft., and shows very good agreement with the modern momentum equation:

$$\frac{W}{(HP)_i} = 550\,\frac{2}{W/A}.$$

Paul Cornu.

It was in 1907 that the French experimenter, Paul Cornu, completed the first really large helicopter which showed any

signs of success. The mechanism was equipped with a 24 horsepower Antoinette airplane engine, was constructed of a steel tubing framework and had a seat for a pilot. There were two two-bladed lifting screws turning in opposite directions, one in front of the other, of approximately 20 foot diameter each. In this machine there was an attempt to realize forward flight as well as vertical lift. Under the lift screws, two tilted wind vanes deflected backward and downward the slipstream from the screws and thus tended to move the machine forward, although the driving force was necessarily very weak and never really functioned, for the contraption was never in the air for long enough periods.

However, the machine did develop lift to the extent of about 520 pounds, which was a little more than the weight of the machine and, on one occasion, developed a lift of 720 pounds for a few seconds. The machine was extremely unstable and could not in any manner be controlled.

It is not my purpose to recite all of the experimental developments in the progress of the helicopter; in the first place because they are altogether too numerous and, secondly, comparatively little real progress has been made even to date, owing, as will be seen later, to a lack of appreciation of the complex problems involved.

Breguet.

Comment should be made of the work of the famous French airplane constructor, Breguet, whose airplanes have been far more successful than his helicopters. Breguet's machines usually consisted of large biplane rotating wing systems weighing from 1,200 to 1,300 pounds. The machines reached a height of about 4 feet and required three or four assistants to steady them while in the air.

Petroczy-von Karman.

Perhaps the most interesting helicopter experiments so far on record were those carried out during the war by Lieutenant Petroczy, chief balloon pilot instructor in the Austrian Ministry of War. It was his purpose to construct a vertical lift machine which could be flown captive and would replace the highly vulnerable captive balloons. Most of the technical

work was carried out by Professor von Karman, who has since come to the United States and is engaged in research work in aerodynamics at the California Institute of Technology.

After considerable experimental work, the construction of two full-scale machines was undertaken, the first to be powered by an electric motor and the second by gasoline engines. Since the electric power plant was not very successful, we shall refer here only to the results obtained with the second machine.

This machine, shown in the photograph, consisted of a framework having three arms of steel tubing supporting

Petroczy-Karman Captive Helicopter. Flew, 1916; total load (with useful load equivalent to 4 passengers) 4,000 pounds, altitude 162 feet; duration with lighter loads was one hour.

three le Rhone rotary engines of 120 horsepower each. These three engines drove, through bevel gearing, the two concentric shafts for the superimposed wooden airscrews, which turned in opposite directions to eliminate the torque reaction of the engine—the reaction tending to cause the machine itself to turn in the opposite direction from that of the screw. The airscrews were 20 feet in diameter and turned at about 600 r.p.m. Under the machine was placed a large shock-absorbing balloon, maintained under pressure by a motor-driven pump.

The observer's nacelle was located above the airscrews and attached to the frame through the interior of the hollow drive shafts. The machine was supplied with a parachute of about 2,700 square feet in area, capable of retarding the fall of the entire machine in the event of engine failure, while, in addition, the observer carried a smaller individual parachute. The helicopter was capable of operating on any two of the three motors.

The helicopter was released at the end of a captive cable actuated by a winch. It was capable of rising to a height of about 160 feet at a speed of 4 ft./sec. Its most successful flights were during April, 1916, when it made a number of ascents of as much as 60 minutes' duration. So far as I know, the machine was usually flown with a dead load for experimental purposes, but it lifted the equivalent of four men, making a total gross lift of about 4,000 pounds. It will be seen that this represents a disc loading of about 12.7 lb./sq. ft., which, according to the momentum equation already quoted, gives 10.5 pounds as the expected lift per induced horsepower. The actual lift recorded was 11 pounds per total horsepower. The discrepancy is undoubtedly to be accounted for by the ground effect, which can increase lift by as much as 20 per cent. Furthermore, the effective disc area is increased when two superimposed airscrews are employed, so that the above estimated disc loading would not be strictly accurate.

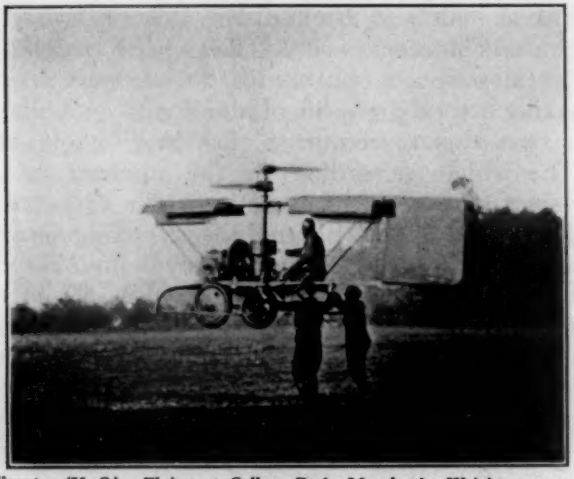
The Petroczy-Karman helicopter is still the holder of the altitude record for helicopters. No attempt was ever made to fly the machine horizontally, which it most certainly would have proved quite incapable of accomplishing, and the fact that the machine was constantly held captive to a series of three cables prevented its instability—for undoubtedly it was unstable—from becoming apparent.

Berliner.

In 1920 to 1923, the American engineer, Henry A. Berliner, whose father invented the Victor Phonograph, constructed and experimented with several types of helicopters, the work being carried on in collaboration with his father. Many of their tests and experiments were carried on in strict secrecy on the outskirts of Washington, and when their results were first divulged, their machine turned out to be a small mechanism consisting only of essentials, but including a seat for a pilot.

Again, as in the work of other experimenters, the torque reaction was eliminated by the use of coaxial airscrews. These were two-bladed wooden screws of about 13 foot diameter, driven by a rotary le Rhone, 80 horsepower engine. The

machine was equipped with a vertical rudder, and with small horizontal vanes for control in vertical flight. The total weight of the machine was approximately 900 pounds, and



Berliner Helicopter (U. S.). Flying at College Park, Maryland. Weight 900 pounds, power 80 horse-power. Altitude 5 feet; duration several minutes.

while it lacked stability, the machine actually flew, at one time rising to the height of a tree in a flight of several minutes' duration.

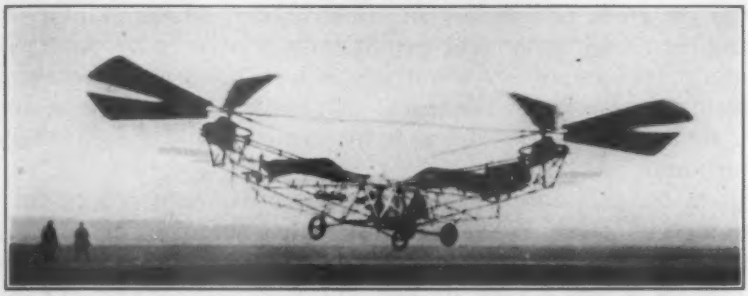
Two years later, Berliner constructed another helicopter, in which he relinquished the idea of coaxial screws and employed two lift screws located on an out-rigger structure around a central airplane type fuselage. The screws were driven through suitable gearing, and while this machine, too, was quite unstable, it did perform several short flights. These flights were made at College Park, Maryland, in June, 1922.

de Bothezat.

One of the most elaborate programs of helicopter development ever undertaken was that carried out by the Russian engineer, de Bothezat, in 1921 to 1923, at Dayton, Ohio, under the auspices of the United States Army Air Corps.

The machine, which is shown in flight in the photograph, consisted, in essentials, of four six-bladed, supporting air-screws, or rotors, of about 25 foot diameter each, mounted at

the extremities of four triangular arms of steel and aluminum tubing. They were driven through suitable gearing and shafting by a rotary, 220 horsepower engine.



De Bothezat Helicopter. Jan. 1923, lifted two persons, altitude 4 feet, maximum altitude 10 feet. Total load 3,750 pounds.

An interesting feature of the design was an attempt to secure stability by sloping the respective axes of the four screws inward, in order that the imaginary lines drawn through these axes would meet at a point, in space, directly over the center of gravity of the machine. In addition, it carried, also, two propellers on horizontal axes, which provided for turning the machine in this or that direction, with two small variable pitch propellers placed over the central gear box to serve as a governor for the engine.

The main lift screws had a differential variable pitch mechanism under the control of the pilot, which was intended to stabilize the machine and, at the same time, enable the entire structure to be tilted in any direction, and in that way produce a horizontal force to permit forward flight.

The total weight of the machine, ready to fly, including pilot and fuel, was 3,600 pounds.

In the course of a test performed by the Technical Section at McCook Field, Dayton, Ohio, on December 18, 1922, the de Bothezat helicopter rose to about 6 feet, and stayed in the air for one minute, 44 seconds, displaying considerable inherent stability. Colonel T. H. Bane of the Air Corps was the pilot, and he was able to bring the machine quite gently to earth.

On another occasion, in 1923, the machine lifted two

persons to a height of 4 feet, for a total weight of 3,750 pounds, and then executed several flights with only the pilot on board, attaining a maximum height of 10 feet.

The principal criticism that one can make of this machine was its great complexity of construction, which manifested itself in a high structural weight for a relatively low factor of safety; various parts of the structure were continually breaking during the course of the tests. Moreover, the plan form and section of the rotor blades were by no means well chosen for the purpose.

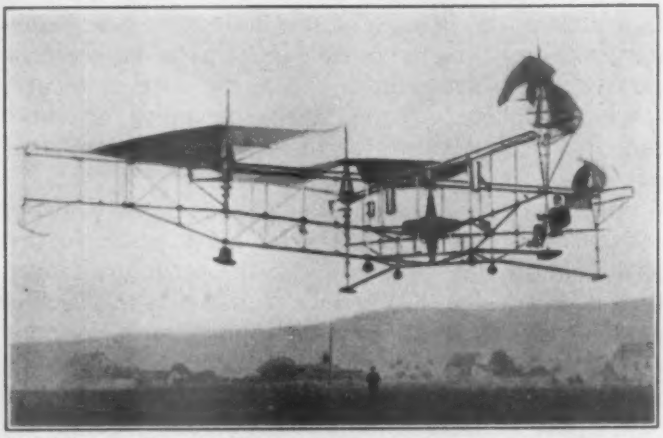
As for the stability of the machine, it could not be fully verified in the course of the short flights made. This method of converging lift screw axes has the disadvantage, so far as stability is concerned, in that the stabilizing forces do not come into play until the machine has acquired a movement of translation and, therefore, the stabilizing forces are considerably delayed. The fact that the machine had a very high moment of inertia, rather than its aerodynamic design, perhaps accounted for what stability was exhibited. Be all this as it may, the de Bothezat helicopter undoubtedly marked an important step in the development of rotating wing aircraft.

Œhmichen.

Etienne Œhmichen, engineer of The Peugot Company in France, began his researches in aviation shortly after the war, by studying the flight of insects and birds. This study led him to a theory which he called the "Recuperation Theory," and according to which the alternate motions of the wings of birds were combined in such a way that they recover, during the backward stroke, a part of the energy delivered to the air during the forward stroke. If he had applied that theory to the construction of helicopters, it would have led Œhmichen to make lift screws with beating or oscillating blades and, in fact, he actually tried to do this, but gave up the attempt because of the complicated nature of the mechanical problems associated with any alternating movement of the blades.

Subsequently, Œhmichen experimented with a great many models, and finally built a combination helicopter airship, using a large, gas-filled balloon to develop part of the vertical lift desired.

In 1922, Œhmichen undertook the construction of a second machine, as shown in the photograph. This machine had 4 main lift screws of two blades each, two of which were 21 feet in diameter, and two 25 feet in diameter. The machine also had five small horizontal propellers with variable and



Oehmichen Helicopter (French). Weight 4,400 pounds; 120 horse-power. Flew a closed one kilometer circuit, May 1924.

reversible pitch—two in front, one in back, and one on each side, the purpose of which was to maintain the horizontal attitude of the machine in flight, and to correct for external air disturbances. Finally, there were two propulsive screws of fixed pitch placed on each side of the framework, and a steering propeller placed in front and serving to direct the machine by making it swing around a central, vertical axis.

The lift screws and all of the eight additional propellers for stabilizing and control purposes were driven by gearing and belts from a central, 120 horsepower, le Rhone rotary engine, placed horizontally in the center of the structure and surmounted by a gyroscopic stabilizer. The total weight of the machine was 4,400 pounds.

In all, this machine made over one thousand flights, the durations of which were several minutes each. The first flight, which lasted for five minutes in hovering, was made in May, 1923. The pilot then undertook to execute straight-line flights, and toward the end of 1923, he succeeded in making a

number of closed-circuit flights, all of about a half mile, at altitudes varying from three to nine feet off the ground. Finally, on May 4, 1924, at eight o'clock in the evening, the Œhmichen helicopter established an official closed-circuit record of one kilometer, the ship flying around three pylons, marking the triangular course. This memorable performance marks a day in the history of the helicopter. It came just twenty years later than the realization of a similar performance by the Wright brothers in 1903, in the first man-carrying, fixed wing airplane. Nevertheless, in spite of this first success, the evolution of the helicopter has remained extremely slow.

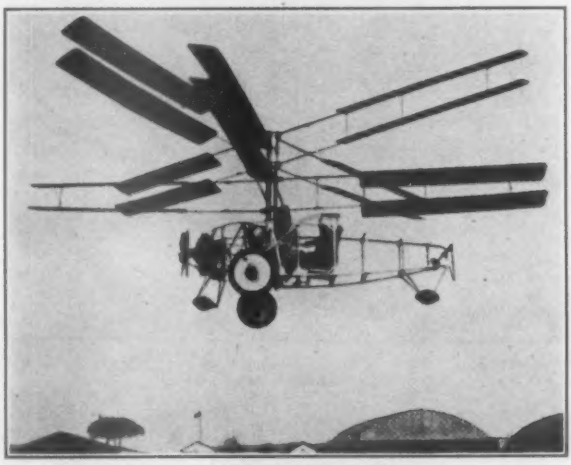
A number of very useful conclusions were drawn from these experiments, but by far the most praiseworthy accomplishment, in my opinion, was the structural ingenuity involved in the design. When we realize that the mechanism included no less than 13 transmission systems (four for the lift screws, eight for the small stability and control propellers, and one for the gyroscope), and that all these stood the "racket" quite well, one admires the skill and ingenuity of the designer, even if one must admit, in the light of modern experience, as we shall endeavor to see later, that the contraption was altogether too complicated.

According to information supplied by the constructor, who always piloted his own machine, the maximum performances achieved were of 13 to 14 minutes' duration, approximately 50 feet altitude, a little over a mile maximum distance covered, and about 400 pounds useful load, in addition to the pilot. The aggregate flying time adds up to about thirty hours.

Pescara.

At about the same time, but extending over a longer period, the Spanish engineer, Pescara, built a number of helicopters, usually with four-bladed, biplane rotors, operating on concentric transmission shafts. One of the most promising machines built was in 1926. It weighed 885 pounds, was powered by a 40 horsepower motor, and was furnished with a tractor propeller which could be engaged, if desired, to permit forward flight. This machine made flights of several minutes' duration to altitudes of 25 feet, or so.

It is interesting to record that the Pescara machines were among the first to employ an over-running clutch device, which, with a change in pitch angle of the blades, permitted the machine to descend safely, in the event of engine trouble.



Pescara (Spanish) Helicopter (1926). Weight 885 pounds; 40 horse-power. Made flights of several minutes duration to altitudes of 25 feet.

His experimental work, however, was marred by a number of accidents, resulting from machines capsizing; but the model S-4, shown in the photograph, exhibited a little more stability and maneuverability than its predecessors. The disc loadings were of the order of about 4¼ pounds per square foot; the induced lift per horsepower about 18½ pounds, and the actual lift only 10 pounds per horsepower. This poor lifting performance per horsepower was undoubtedly due to high gear losses and the high parasite drag of the rotor system.

D'Asconio.

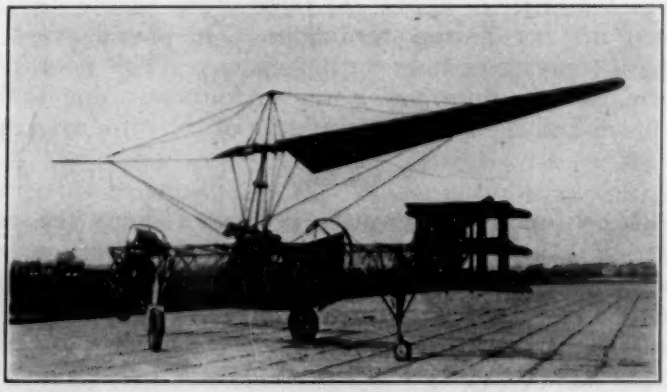
This helicopter is interesting because it shows the use of feathering blades. Like the others, the machine was extremely complicated mechanically and suffered materially thereby, but it did perform a number of very interesting flights.

von Baumhauer.

von Baumhauer, The Director of the Dutch Aeronautical Research Society, built a helicopter in 1930, which I am show-

D'Asconio Helicopter, 1930. Flew in Italy, October 8, 1930. Altitude 59 feet, distance 3,500 feet, duration 8 min. 45 sec.

ing rather because it is illustrative of what not to do. The machine had a single, two-bladed rotor with feathering blades. This was driven by a long shaft from a radial motor located, for reasons of balance, at the end of a long structural arm. At the opposite end of the basic fuselage structure of the machine was another motor, with its axis at right angles, the purpose of which was to counteract the rotor torque, a purpose



von Baumhauer Helicopter (1930). Director, Aeronautical Research Society, Holland.

of which it was quite incapable, in view of the fact that herein is an effort to correct a moment with a force, thereby breaking a fundamental mechanical law. This matter we shall have occasion to discuss later.

de la Cierva.

Though chronologically out of order, I have intentionally left until now any mention of the Cierva autogiro, the only rotating wing aircraft developed to date which can be said to have been lastingly successful in so far as its development

Early Cierva Autogiro (1928). The first autogiro to fly in America.

to date has progressed. In presenting to you the autogiro, I am moved by a sincere and great respect for Senor Juan de la Cierva, the inventor of this type of aircraft. It is impossible for one to indulge in an intensive study of the theory and development of the autogiro without becoming deeply imbued with admiration for the untiring efforts of this distinguished Spanish engineer, who, in the face of tremendous technical and material obstacles, succeeded in making really practical a form of flight far-reaching in its revolutionary influence upon all former and many current conceptions of air travel.

In 1919, Senor de la Cierva first began experimenting with the idea of a windmill lifting-system rotating freely about a vertical or nearly vertical axis under the influence of the

vertical component of the relative wind created by forward motion. Cierva, in common with other experimenters, was faced with the problem of asymmetry of lift on a rotating system due to the differences in relative wind on opposite sides of the cycle of rotation, resulting from the fact that on one side the blades move into the relative wind while, on the other side, they travel with the relative wind.

Cierva's first solution of this problem was not successful, but it led him to the invention of the fundamental characteristic of his autogiro. While the use of two windmill systems mounted concentrically one above the other on a common shaft and designed to rotate in opposite directions was originally proposed and tried out as a solution to the lack of symmetry in the resultant lift of a single windmill, this did not prove satisfactory owing to the interference effect which caused the lower windmill to turn at a speed of only about two-thirds that expected. Thus, the unbalanced lift-forces were not corrected, and other means were sought.

Kellett Autogiro, Type K-2 (1931).

Study of the blade-element theory of airscrews led to the realization that increased lift, resulting from greater relative

air speed, could be compensated by decreased effective angle of incidence and that, by applying this interrelationship between velocity and angle of incidence to geometrically opposite blades in a windmill system, centralization of the resultant lift-reaction for the whole system could be secured. The result was Cierva's second autogiro, which comprised a single windmill system of three blades mounted upon a standard form of airplane fuselage and tail. The incidence of each blade was controllable by the pilot. This machine failed owing to lack of torsional stiffness in the blades and, presumably, the inability of the pilot to operate satisfactorily an incidence control of this nature.

The idea of hinging the individual blades was first developed by Senor de la Cierva in 1922, and has formed the basis of his successful autogiro development. To prove this

Kellett Autogiro, Type K-3 (1932).

idea, a single-windmill system of four blades was mounted freely on a vertical axis above the fuselage of the machine. The blades, instead of being rigidly attached to the hub, were

mounted on horizontal hinges, giving each blade individual freedom to flap during rotation. Rubber cords were used to prevent the blades from resting on the ground or on other parts of the machine when stationary, while in flight, centrifugal force kept the blades at an attitude approximately perpendicular to the axis of rotation. This form of construction, though greatly modified and improved, remains a feature of first importance in today's autogiro. The result has been a machine of remarkable flying characteristics.

The flying characteristics of the autogiro are today well-known. The freely-rotating rotor system is set in motion prior to flight by a clutch and transmission from the engine, which drives the propeller as in an airplane. Before takeoff, the power transmission to the rotor is disengaged, and thereafter the rotor turns freely. The autogiro flies like an airplane. Relative forward speed, considerably less than necessary in the case of the fixed-wing airplane, is a requisite. Vertical descent is possible but not entirely practical owing to lack of "steerage way," for control. While early autogiros carried ailerons, elevators and rudders, the newest Cierva machines are controlled directly from the rotor by a tilting mechanism which displaces the relative positions of center of gravity and center of lift.

To the advantages of these new "direct-control" autogiros, attempts are now being made to provide momentary helicopter features by means of storing excess kinetic energy of rotation in the rotor prior to starting, and dissipating this energy in a brief vertical hop off the ground, after the power has been disengaged. Experimental flights have been made and work along this interesting line of improvement is progressing currently.

In the meantime, many autogiros have been built in this country and abroad; some are shown in the photographs. Millions of miles have been flown under the rotating blades of the autogiro and a new era of flight has undoubtedly dawned.

A close parallel to the autogiro is the Wilford gyroplane, in which the blades feather rather than flap in the equalization of lift forces between oppositely-disposed blades. In this type, but one of which has to date been successfully flown for short distances, the rotor also turns as a windmill. In this

Wilford Gyroplane (1932).

respect, the gyroplane closely resembles the autogiro, but the rigidity of the rotor is the fundamental difference between the two types.

THE THEORY AND TECHNICAL ASPECTS OF FLIGHT ON ROTATING WINGS.

The basic principles of heavier-than-air flight are exceedingly simple. A nominally flat surface, called an air-foil or wing, when moved in relation to the air and held at an appropriate attitude to the air, will exert an upward force or lift upon which, in an airplane, we are able to fly. Obviously, a wing, at rest, will exert no such lifting force; relative motion is a prerequisite. For a desired lift, the necessary wing area and speed will vary inversely with each other. This is the reason for the comparatively high minimum and landing speeds of airplanes, for there is an airspeed below which there is insufficient lift to maintain the weight.

Since relative motion is essential to the development of aerodynamic lift, it is immediately apparent that were it possible to cause the wings of an aircraft to move, as in rotation, independently of the fuselage or body of the machine, the desired lift force could be obtained, and this arrangement, other things being practical, would render vertical flight entirely feasible.

While the proposition appears to be extremely simple, the almost innumerable attempts to achieve vertical flight have so consistently resulted in failures of one kind or another that the belief has grown among aeronautical engineers that controlled vertical flight, combined with forward speed possibili-

Pitcairn Army Autogiro, Type YG-2 (1936).

ties, is impossible of achievement. However, actual flight experience with the autogiro, while not itself a vertical lift machine, has gone a long way toward substantiating a detailed and accurate theoretical analysis of the rotating wing type of flying machine, while recent additional theoretical work has demonstrated beyond dispute that the attainment of satisfactory lift forces in a power-driven rotating system is aerodynamically practical. Past failures in attempts to achieve

controlled vertical flight have not, in my opinion, been due to unsound fundamentals, but rather to a lack of appreciation of the many detailed difficulties blocking the application of these fundamentals, and perhaps also to a lack of ingenuity in attacking simultaneously the series of mechanical problems involved.

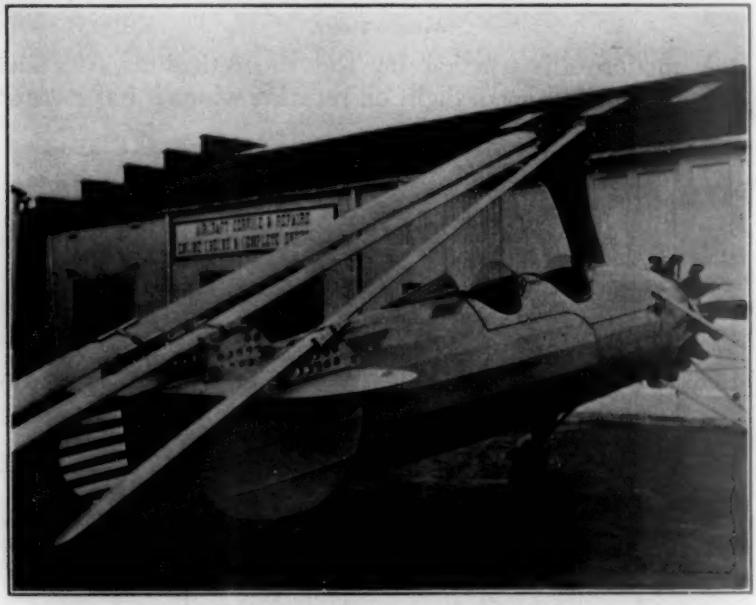
Autogiro Theory.

A modern dissertation on the theoretical aspects and practical possibilities of flight on rotating wings is incomplete,

Kellett Army Autogiro, Type KD-1 (1936).

as well as being poorly founded, if it does not start with the ingenious conception of a freely rotating system of lifting surfaces as developed by de la Cierva. Fundamentally, the principles upon which autogiro flight is predicated are eminently simple and precisely similar to those same principles governing the flight of the now more conventional airplane; however, the form of application of these principles is entirely new.

It will be understood that the details of autogiro theory, particularly as regards the autogyration, or free rotation, of the rotor system, are extremely complex. I propose, however, to set forth an elementary theory which, except in so far as it neglects certain factors which are essential in actual design



Kellett Army Autogiro, Type KD-1 (1936).

calculations, is satisfactory in conveying a general understanding of the operation of a freely-rotating windmill as a lifting system. It should be pointed out that the theory of the autogiro is not in any way based upon the work of the many experimenters in helicopter flight, some of whose endeavors have been portrayed in the photographs, nor is the subsequent discussion, upon which I shall shortly enter, relating to the promising prospect of real vertical flight, based entirely upon the Cierva theory, though necessarily drawing heavily from it.

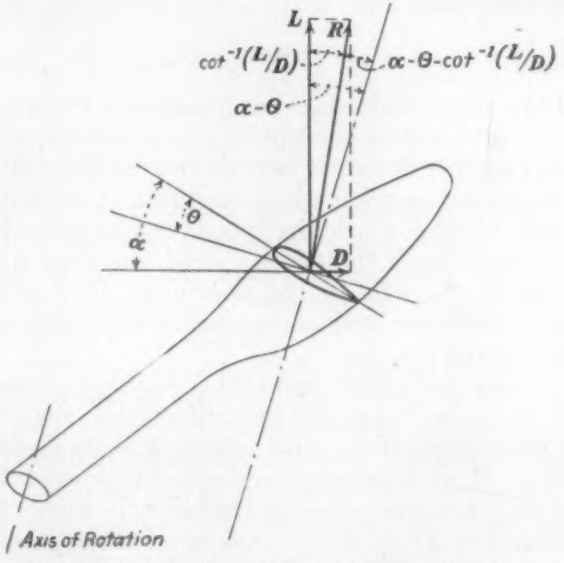
In the diagram (Fig. 1), the forces acting upon an autogiro rotor blade in steady flight are shown. The axis of rotation is

indicated and the relative wind V, caused by the rotational velocity of the blade—which is assumed—and the translation speed of the machine, is shown. The blade has an angle of pitch θ referred to the perpendicular to the axis of rotation, and an effective angle of incidence α which includes θ and which is caused by the backward slope of the axis of rotation. There will be lift (L) and drag (D) forces on the blade, these being, respectively, perpendicular to and parallel with the relative wind.

It will be seen that the lift vector (L) makes with the parallel to the axis of rotation an angle equal to $(\alpha - \theta)$, while the resultant force (R) slopes back from (L) through the angle whose cotangent is the L/D ratio of the section $[\cot^{-1}(L/D)]$ at incidence α. Thus, for autogyration, it is necessary only that:

$$[\alpha - \theta - \cot^{-1}(L/D)] = > 0.$$

FIG. 1.



Forces acting upon the autogiro rotor blade in steady flight.

Under these circumstances, there will be an accelerating force acting on the rotor blade. Neglecting frictional losses,

in order that the rotation thus created shall be steady, without acceleration or deceleration:

$$[\alpha - \theta - \cot^{-1}(L/D)] = 0$$

and R now lies parallel to the axis of rotation.

Assuming that there be no angle of pitch to the blade ($\theta = 0$), the condition of steady motion becomes:

$$\alpha - \cot^{-1}(L/D) = 0$$

or,

$$\alpha = \cot^{-1}(L/D).$$

In other words, for steady rotation of the system, the effective angle of incidence must equal the angle whose cotangent is the L/D ratio of the section at that angle of incidence; a condition which, for most wing sections, precludes the possibility of the blade operating at or near its maximum L/D ratio, unless θ is given an appropriate value. The pitch angle θ is, therefore, made such that:

$$\theta = \alpha - \cot^{-1}(L/D)_{\max.}$$

We have thus established an elementary theory which is sufficient to give a clear conception of the conditions required for autogyration. It should be remembered that the autogiro is best considered as always in a condition of vertical descent of varying degree, depending upon the magnitude of the vertical component of the relative wind, resulting from backward slope of the axis of rotation. In other words, it is mandatory that there shall always be a component of velocity upwards through the disc.

If we now superimpose upon this condition a translational velocity, we immediately fall into difficulties, the solution of which is the outstanding characteristic of Senor de la Cierva's inventions. If, for example, the speed of rotation Ω at a given radius in the rotor system is equal to twice the forward speed of translation, $\Omega = 2V$ or $\Omega/V = 2$, it is clear that there will be an asymmetry or absence of proportional lift on the rotor system due to the fact that, for all blade elements at this radius, the resultant velocity on the two sides of the cycle, with respect to the line of flight, will be in the relationship of

3 : 1, as indicated in the diagram (Fig. 2). The rotor blades are, however, free to flap about horizontal hinges at their roots, and perfect symmetry of lift is obtained at the expense of a little lateral tilting of the resultant force or thrust for the

FIG. 2.

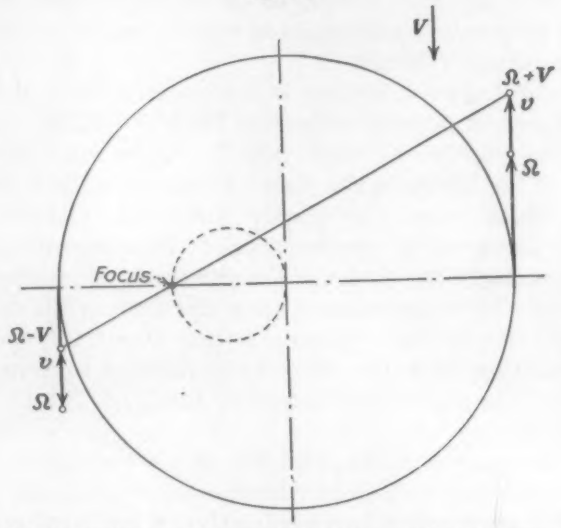


Diagram showing cause of asymmetry in lift in a rotating lifting system.

whole rotor system. The blade approaching into the relative wind is subjected to increased lift due to the increased speed and, being hinged, rises with corresponding decrease in its effective angle of attack. The blade, accordingly, operates at a lower point on the lift curve.

The reverse takes place on the opposite side of the cycle. We get, therefore, a condition of increased lift due to increased speed, but a lower lift-coefficient on one side and decreased speed and higher lift-coefficient on the reverse. The effect is a constant tilt of the disc of rotation when viewed along the flight path, but the lift or thrust vector passes through the hub.

It will be realized that elements of the blades at short radii will stall at some point in the cycle, and that on the downwind side of the cycle certain portions of the blade will be standing still or moving backward in the relative wind. This point of

zero velocity, termed the "focus" (see Fig. 2), is an important characteristic of the autogiro, and its position is governed by the relation Ω/V which, for efficiency, must not be less than $\Omega/V = 1.5$. The higher the value of Ω/V, the closer does the focus come into coincidence with the true center of rotation. This relationship fixes certain of the characteristics of a given autogiro to obtain a required top speed, and is a controllable factor in autogiro design.

In the autogiro, a further articulation, a vertical hinge, in the rotor system permits respective blades to move in the plane of rotation relative to each other. There are two distinct motions of the blades in the plane of rotation in addition to the rotation itself. One, of purely kinematic character, is a result of the peculiar combination of flapping, rotation and upward coning of the blades of the autogiro. The other, which is algebraically superimposed upon the first, is the oscillation of a blade due to the changing torque about the root of the blade resulting from the periodic variations in aerodynamic blade drag throughout the cycle of rotation. Both motions are periodic.

The kinematic oscillations are of an extremely complex nature, but I shall endeavor, with the aid of a diagram (Fig. 3), to describe their origin in a qualitative, if not mathematically quantitative, manner. These kinematic oscillations are caused by the fact that the flapping of the blades has the effect of tilting the cone of rotation backwards and to one side, with the result that the individual blades, or rather their centers of mass, while actually turning about the hub of the rotor system, are virtually in rotation about an imaginary point located in space in the center of the cone. Through this virtual center of rotation, the inertia or centrifugal forces pass, with the result that, when viewed in the plane of symmetry, these forces do not act along the axes of the individual blades. Consequently, without the vertical articulations at the blade roots, powerful bending moments would be set up in the blades which would not only cause violent structural stresses, but would create a roughness in operation of the system which would be quite intolerable from the point of view of flying. The vertical articulations relieve the blades of these stresses and, though floating freely in space in both a vertical and

horizontal plane, the blades rotate while at the same time repeating a cycle of events about both horizontal and vertical hinges which never get out of phase and which, with proper design, will never reach a condition of undamped resonance.

FIG. 3.

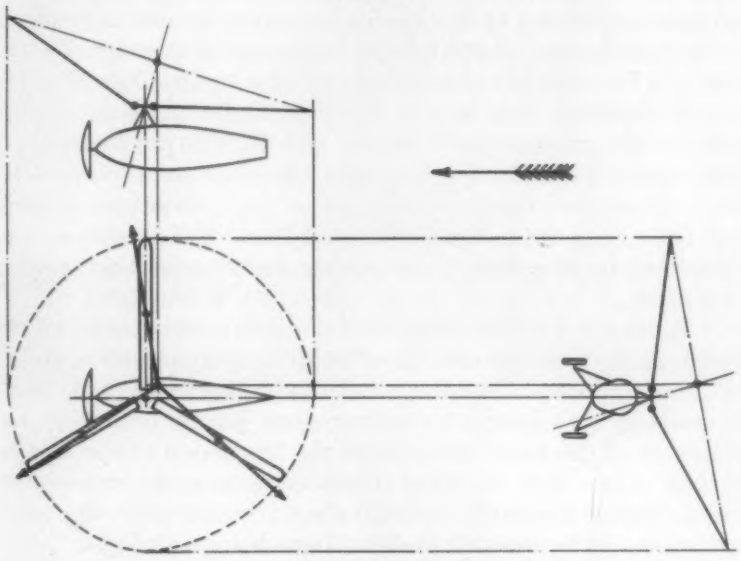


Diagram showing origin of kinematic oscillations.

It is clear that, by reason of the hinges at the blade roots, each blade is, in reality, a free pendulum with the gravitational force on the pendulum replaced by the centrifugal force of rotation. Provided the speed of rotation is constant, the horizontal pendular frequency of the blades will remain constant; but, in flight there are conditions under which the rotational speed will change as, for instance, with change in forward speed when the vertical component of velocity through the disc changes. Now, it will be evident that, in view of the cyclic character of the series of aerodynamic events which takes place during each complete rotation of the system, a very close relationship must necessarily exist between the natural pendular frequency of the blades and the periodicity of these events, which is a function of rotor speed; otherwise, an un-

damped resonant oscillation of the blades could very readily be set up.

As already pointed out, the rotor speed is a function of the aerodynamic design and, provided this speed remains constant, the pendular frequency of the blades will remain constant. In order to avoid resonance in the rotor system, the natural pendular frequency of the blades must be carefully selected in the initial design, the selection being made possible by the choice of location of the vertical articulation in relation to the axis of rotation. Obviously, the distance between the central axis of rotation and the vertical articulation pin fixes, for a given rotor diameter, the length of the blade as a free pendulum. Thus, for any given rotor speed (and, therefore, centrifugal force) the natural periodicity of blade oscillations can be controlled in the design by proper location of the vertical hinge pin.

Experience has indicated that the natural frequency of the blades as vertical pendulums should be an even harmonic of the rotor speed. The sixth harmonic has been used very successfully and has given very smooth rotors. In this case, the speed of the rotor is six times the frequency of the blades. In such a case, with the rotor speed constant within reasonable limits, blade resonance is unlikely to occur, and the rotor operation will be smooth under all conditions of flight.

As we have seen, the original Cierva conception was that of an aircraft deriving its lift entirely from a rotating wing system. The necessity of ailerons for lateral control led to the addition of a very small fixed wing capable of carrying these control surfaces, and it became apparent that, while not essential to the flight of the autogiro, the fixed wing was capable of controlling and stabilizing the behavior of the blades and the speed of rotation of the system. It must be remembered that a properly-designed wing surface will always exert a lifting force when set at an appropriate angle to the relative wind. A freely-turning rotor system, on the other hand, turns because it lifts and, paradoxical as it may seem, lifts because it turns. Its speed of rotation will vary with the product of the weight of the load it is carrying and the vertical component of velocity through the disc of rotation. If the fixed wing surface is so designed as to rob the rotor of weight to

lift at the high speeds in horizontal flight and, in a dive (when the angle of attack of the rotor may become very small), to add weight by exerting a negative lift, the speed of the rotor can be maintained constant within narrow limits, and the periodic oscillations of blades are, thereby, controlled.

With the development of the "direct control" type of rotor system, in which, as we have seen in the photographs, the tilting of the rotor hub provides the desired longitudinal and lateral control forces, one of the purposes of the fixed wing, with its ailerons, has disappeared, and the wing has been eliminated in this new type. The flying characteristics of the autogiro have not materially changed since the wing carries only a small proportion of the lift. But, to what extent the mechanical reliability and aerodynamic efficiency of the autogiro may suffer is, in my opinion, still an open question. While recognizing that the saving in weight and in head resistance, attendant upon the elimination of the fixed wing, are worthy reasons for this simplification, I see, in the loss of the wing in combination with the rotor, evidence of a reduction in aerodynamic efficiency, when expressed in terms of the L/D ratio for the whole machine, which exceeds the benefits of weight and resistance saving.

Unlike a fixed wing surface, the L/D curve of the autogiro rotor reaches a maximum and, thereafter, due to parasite drag, remains almost constant over the speed range from climbing conditions to full-speed flight. Thus, while the fixed wing airplane has its maximum L/D ratio under climbing conditions, and at full speed is operating at distinctly reduced aerodynamic efficiency, the autogiro flies at its top speed under conditions closely approximating maximum efficiency.

Because, under all conditions of flight in a properly-designed autogiro, the incidence of the rotor system determines the attitude of the rest of the structure, it is possible to design and arrange the fixed wing such that, in flight, it will meet the air at the angle of attack corresponding to its maximum L/D; in other words, at climbing attitude, even though the autogiro, as a whole, is flying along a horizontal path. Thus, the fixed wing, too, will be at maximum speed under conditions of climbing efficiency and, consequently, the overall L/D of the autogiro will be raised. For this reason, and for

the purpose of avoiding a wide range of rotational speeds in the rotor, and the possibility of resonance at top speeds, which could cause a rotor blade structural failure, it is my belief that a properly-designed small fixed wing is always advantageous in the autogiro, even in the new "direct control" types.

The Helicopter.

The development and success of the autogiro has again drawn attention to the possibilities of the helicopter. The autogiro has seemed, perhaps, the ideal solution for the rotating wing flying machine. Certainly, its extraordinary flying qualities, its availability, its utility and its inherent safety, largely due to its ability to slow down in flight and descend to earth almost vertically, are all highly desirable characteristics for an aircraft.

The so-called "hop-off" feature, the latest autogiro development, in which kinetic energy of rotation is stored in the rotor during the starting operation and a momentary change of blade pitch provides temporary vertical lift until the stored energy is dissipated, is interesting, and if it proves ultimately to be entirely practical, even in still air, will greatly augment a picture of the future already fascinating in its possibilities; but the prize wrapped up in the helicopter is still a challenge to many of us. Vertical lift as well as vertical descent, hovering flight and the prospects of still greater speeds for the rotating wing type, are trophies well worth the effort, and in this effort autogiro experience cannot fail to play an important part.

Hovering Flight.

In order that there may be no misconception in regard to the fundamental requirement of vertical lift or thrust from a power-driven rotating wing system, let us first analyze briefly the mathematical relationships involved. For this approximate analysis it may be assumed that the power required to develop a thrust is made up of two parts, induced power and profile power. From the momentum theory, the induced power in vertical flight is given by the expression:

$$P_i = W\sqrt{\frac{W}{2\rho A}},$$

where W is the weight, A is the disc area, and ρ the air density. If

$$W = \rho T_c A \Omega^2 R^2,$$

where Ω is the angular velocity, R the disc radius, and T_c the thrust coefficient, then,

$$P_i = \rho T_c A \Omega^3 R^3 \sqrt{\tfrac{1}{2} T_c}.$$

If C_{D_0} is the mean profile drag coefficient and c the blade chord, the profile power element is

$$dP_p = \tfrac{1}{2}\rho C_{D_0} c \Omega^3 r^3 dr.$$

Then, for the whole airscrew, integrating, first over the whole blade and then over the complete revolution:

$$P_p = \tfrac{1}{8}\rho C_{D_0} \sigma A \Omega^3 R^3,$$

where σ is the solidity, or ratio of actual area to swept area of the rotor. The total power then is:

$$P = P_p + P_i = (\tfrac{1}{8} C_{D_0} \sigma + \sqrt{\tfrac{1}{2}} T_c^{\frac{3}{2}}) \rho A \Omega^3 R^3$$

or, in coefficient form:

$$P_c = \tfrac{1}{8} C_{D_0} \sigma + \sqrt{\tfrac{1}{2}} T_c^{\frac{3}{2}}.$$

Vertical Climb.

In vertical climb the momentum equation becomes

$$W = 2\rho u (A + 2RV)(V_c + u),$$

V_c being the climbing velocity. The power available for climb is:

$$P_c = W(V_c + u)$$

and, P_a being the total power available,

$$P_c = P_a - P_p' - P_s.$$

Combining and solving,

$$V_c = \frac{P_c}{W}\left\{1 - \frac{W^3}{2\rho P_c^2 (A + 2RV)}\right\}.$$

Applying these expressions to a hypothetical 3,000 pound helicopter of 300 horsepower, with a transmission and cooling efficiency of 80 per cent. and a 44-foot rotor diameter, we find that we are able to develop a rate of vertical climb of approximately 1,600 feet per minute.

It is evident, therefore, that vertical lift from a power-driven rotating wing system is entirely feasible and, in fact, a quite surprising performance in this respect can be anticipated. This has proved highly encouraging in the study of vertical flight, even without regard for the several cases, which we have already cited, in which the vertical thrust of rotating systems has been practically demonstrated. Notably, in this regard, we can recall the case of the captive Petroczy-Karman helicopter, which has more recently been developed into the partially successful Asboth helicopter.

Overcoming Past Failures.

In view, however, of the large number of helicopter failures, it would seem appropriate to use, as a basis for a discussion of the possibilities of vertical lift aircraft, a recital of the causes of failure and an explanation of the means and methods whereby, in the light of present knowledge, a repetition of these failures may be avoided. The principal causes of helicopter failures may be classified as:

(*a*) Failure to balance rotor torque;
(*b*) Excessive rotor disc loading;
(*c*) Inefficient utilization of power;
(*d*) Mechanical complexity;
(*e*) Excessive weight and parasite drag;
(*f*) Gyroscopic precession in the rotor system;
(*g*) Instability and ineffective control.

(a) Failure to Balance Rotor Torque.

It has seemed strange that the torque reaction tending to revolve the aircraft in the opposite direction from that in which the rotor system is driven, has proved to be one of the greatest obstacles to successful helicopter flight. The principal methods adopted for balancing the torque reaction have been:

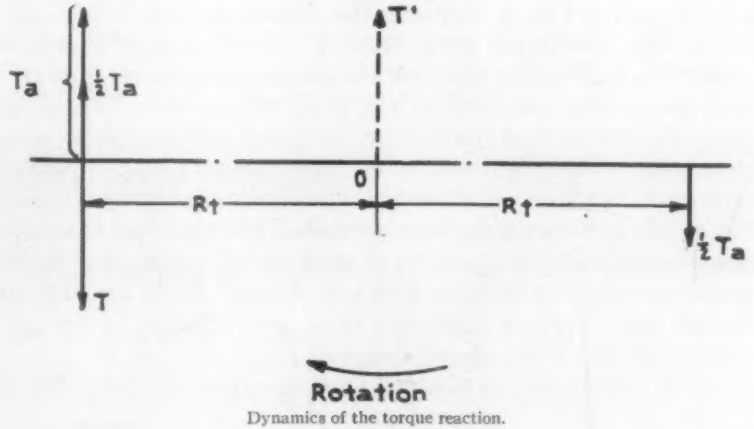
1. Two coaxial lift screws rotating in opposite directions;
2. Two or more non-overlapping lift screws;
3. A rotor system driven by individual blade-tip propellers actuated independently or geared to a central power plant.

All of these lead to serious weight, mechanical and control problems. The first two arrangements, namely, multiple rotor systems, involve high disc loadings and are fundamentally deficient in stability, while all of them are prohibitively wasteful of power.

It appears that the only satisfactory method of reacting the rotor torque is with the aid of symmetrically-arranged anti-torque surfaces, which function as wing surfaces in the slipstream or down draft from the rotor itself.

The method of using anti-torque surfaces is not new, but the only practical arrangement has, so far as I know, never before been proposed. To arrange anti-torque surfaces on one side only of the rotor axis as, for instance, at the tail of the ship, which is the most usual proposal, is to attempt unsuccessfully to break a fundamental mechanical law. We cannot balance a moment or couple with a force; we must create a couple to balance a couple. Therefore, the anti-torque surfaces must be arranged symmetrically about the axis of the torque reaction. This will be clarified by a consideration of the force diagram shown in Fig. 4.

FIG. 4.



Dynamics of the torque reaction.

The torque reaction force, T, is considered as concentrated at radius R_t from the rotor axis O. The disposition of anti-torque surfaces at the tail only gives rise to the force T_a, equal and opposite to T. Such an arrangement, as already stated, neglects the fact that the torque reaction is a couple and, therefore, cannot be treated as a single force. When represented as concentrated and acting at a point, as in the case of T, a second force T' must be implied to complete the couple. Obviously, this force T' is not neutralized by T_a and will in practice cause a violent tendency to side-slip, that is quite impossible to handle.

The correct solution is found by opposing T with a couple instead of a single force. Thus, the equal and opposite forces $\frac{1}{2}T_a$ spaced at distances R_t each side of O give rise to a couple having moment $2R_t \cdot \frac{1}{2}T_a$ which exactly balances the moment of the torque reaction couple, TR_t.

The forces $\frac{1}{2}T_a$ need not, of course, be applied at equal distances from O provided their spacing is $2R_t$, but clearly the simplest and most economical arrangement of the airfoils calls for equal spacing.

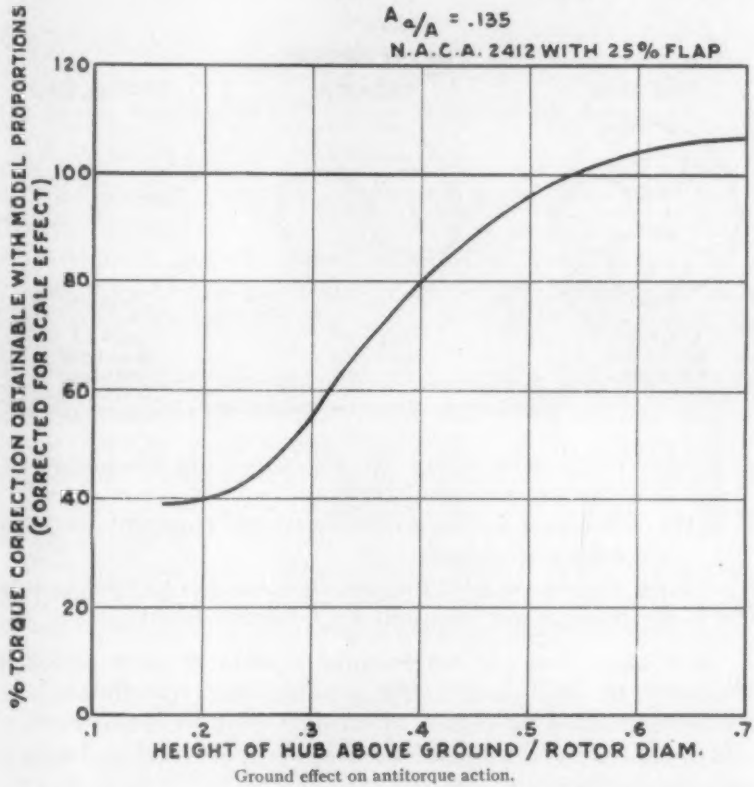
Recent wind tunnel tests carried out to determine the efficacy of the anti-torque arrangement proposed, and particularly to throw light upon the ground effect, have indicated this method to be entirely practical. Obviously, the downwash from the rotor is materially influenced by the proximity of the ground when the ship is at rest. The magnitude of this ground influence upon the proposed anti-torque arrangement is indicated in Fig. 5, showing the results of these tests.

In the particular arrangement tested, complete torque correction is possible only with a ground clearance equal to a little more than one-half of the rotor diameter. This is appreciable and would result in a high and rather cumbersome structure. The possibilities of improvement are, however, apparent, and some of these will have been tested by the time this paper is presented and recorded. The problem is simply one of securing the required magnitude of cross-wind forces from fixed and adjustable surfaces located in an air stream. Aspect ratio, surface flaps and slots, and location of area are among the variables at our disposal.

It is interesting to observe that the slope of the curve of

Fig. 5 from the point of 80 per cent. correction shows that if flaps or slots, or a combination of these, are eventually used in a full-scale machine, there will be a torque control correction

FIG. 5.



Ground effect on antitorque action.

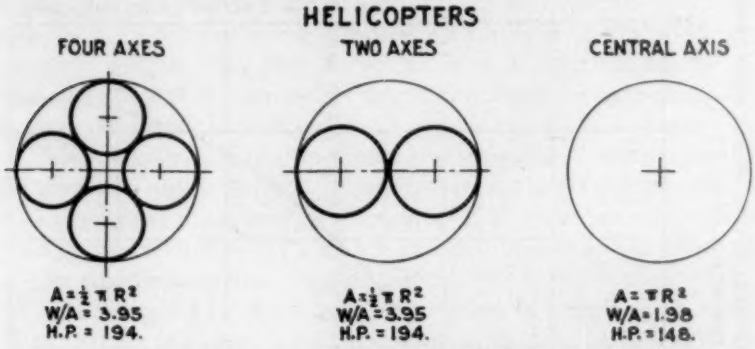
to be made either automatically or from the pilot's seat as the machine leaves the ground.

(b) Excessive Rotor Disc Loading.

Fundamental momentum theory shows that lift per horsepower in hovering flight is an inverse function of disc loading; that is, the weight per square foot of area swept by the rotating blades. If the simplifying assumptions are made that weight is a function of rotor diameter and that profile power loss is

the same in all cases, an interesting graphical comparison of the fundamental lifting efficiencies of various possible arrangements of rotating blades and rotor systems for the helicopter may be made. These arrangements are shown in the diagram (Fig. 6) in which:

FIG. 6



Comparative lift efficiencies of rotating systems.

A is the actual area swept by the revolving blades of the rotating system or systems.
R is the semi-span of the overall system; constant for each arrangement shown.
W/A is the disc loading for the assumed weight of 3,000 pounds.
HP is the horsepower required for hovering flight.

It is clear that the single rotor system is far superior in efficiency to any other arrangement, and its efficiency is further increased by reason of the fact that a central vertical axis of rotation gives considerable savings in structural weight and aerodynamic resistance.

It may be mentioned here that a check of the disc loadings employed in practically every helicopter experiment to date has shown values so high as to leave little or no reserve power. Only with a central axis and a single rotor system can this problem be overcome, and the autogiro may be cited as a practical confirmation of this principle.

(To be concluded.)

THE PETOSCOPE: A NEW PRINCIPLE IN PHOTO-ELECTRIC APPLICATIONS.

BY

ALAN S. FITZGERALD,

Research Associate in Electrical Engineering, Swarthmore College, Swarthmore, Pa.

GENERAL.

The general principle on which practically all photo-electric systems are based is that the photo-cell is exposed to some kind of light effect and that a relay, or its equivalent, is actuated by a variation in the photo-electric current which, in turn, is determined by the amount of light which falls on the cell.

The principal factor in determining the practicability of such systems, is the nature of the controlling light effect and the manner in which it can be exhibited to the photo-electric apparatus. This effect will, in general, be some object or condition which tends to modify the total amount of light which impinges on the cell.

Some degree of variation in the relay current, other than that due to light changes, must be allowed for, such as for example, voltage fluctuations, or changes in the characteristics of tubes, and the like.

Furthermore, light effects, other than that to which the system is desired to be responsive, may be coexistent with the controlling light effect, and the main problem in all such systems is that of devising means for exhibiting the controlling effect to the light sensitive apparatus so as to exclude all other effects or, at least, to arrange that the actuating effect may predominate over all other light effects. In other words, the photo-electric system should be selectively responsive to one particular effect.

Photo-electric applications, in general, may be roughly classified in two groups. First, applications which are concerned with general light intensity, and second, applications which relate to individual or specific light effects.

The first group is exemplified by apparatus for controlling lights in accordance with daylight illumination, or the various industrial applications in which photo-electric apparatus is employed for determining general properties of materials, as for example, color or transparency. Applications of this type are, in general, relatively simple to carry out because the photo-electric cell is rarely exposed to any other optical or luminous effect except that to which it is desired to be responsive.

The second group comprises most of the photo-electric cell applications with which the general public is familiar. In such applications, the photo-electric cell is used for detecting some specific object. Sometimes this object is a discrete, material, object such as an automobile, a person, a package on a belt conveyor, or the like. In manufacturing or industrial applications, attempts have been made to utilize the photo-electric cell for detecting objects which are visual rather than concrete, such as, for example, spots, blemishes or defects in material or manufactured articles.

In photo-electric applications of the second class, which comprise the vast majority, the ease or difficulty with which the application may be effectively carried out, depends principally upon the relative magnitude of the light effects to which the device is required to be responsive and such other light effects to which the photo-electric cell is liable to be exposed.

Only where it is found feasible to arrange that the light effect by which the apparatus is to be actuated preponderates over all other possible changes in illumination, have such applications been found practical in the past.

For example, in applications such as the opening of doors upon the approach of a person, the counting of traffic, and similar systems, the method almost universally employed is to project a beam of light across the path of motion of the object, and to mount a photo-electric cell so that substantially all other light, except that coming from the source of the beam, is excluded. The interruption of the beam of light by the passing object causes a change in photo-electric current of sufficient magnitude for practical use to be made thereof.

The limitations of these methods are obvious. They are,

in general, only applicable where the object to which the photo-electric device is to respond, is constrained to move precisely in a pre-determined path. The photo-electric cell has no wider range of vision than an immovable eye looking through a stationary length of pipe.

Similarly, devices for detecting spots in materials have only proven effective in the past for detecting spots representing, in dimensions, a substantial proportion of the optical field embraced by the photo-sensitive element. Systems intended to detect small spots have not been widely successful, due to the fact that, either they were incapable of detecting spots of the required degree of smallness, or alternatively, in order to be operative in respect to such small spots, a large number of photo-sensitive systems, each embracing a small optical field, or a complicated scanning system, were required to cover the total area of the material to be exhibited. The cost of the latter alternatives has been prohibitive.

The specific problem to which, hitherto, a solution has not been available may be defined as follows:—It has not been known how to provide photo-electric means, suitable for practical application, which is capable of being actuated by an optical effect representing a relatively small percentage of the optical field exhibited to the photo-electric system, and of indeterminate position within this field. More simply expressed, we have not known how to make a system which will approach in any way the action of a biological optical and nervous system which can detect or perceive a relatively small object, anywhere within the field of view, and independent of the amount of light reflected or transmitted by the background or by other objects within the area embraced.

The apparatus described in this paper represents a radically new and different method of applying the photo-electric cell. It is an attempt to employ the photo-electric cell in such a way that its action is much more nearly comparable to an organic or biological eye.

Such an optical organ embraces a wide field of view. In practical applications of the type hitherto known and referred to above, the field of view of the photo-electric cell is no greater than the cross-section of the beam of light. It can only respond to a passing object when such an object com-

pletely occupies the field of view so as to cut off all, or nearly all, of the light reaching the photo-cell. But with even a relatively imperfect biological eye, such as may be found among the less developed organisms, an object occupying only a minute portion of the solid angle which the field of view comprises, may be discerned.

PRINCIPLE OF OPERATION.

Most of the generally employed photo-cell applications, in the past, have been actuated by either an increase or a decrease in the photo-electric current caused by the actuating light effect. They have, therefore, been responsive to a quantitative change. The magnitude of this change is, in general, closely related to the ratio between the extent of the controlling light effect and the total light flux received by the photo-electric cell.

Obviously, for reliable practical results, the percentage change in the relay current which is due directly to the actuating effect, must be substantially greater than that due to all other possible variables. In commercial applications it is apparent, from the above, that unless the actuating effect represents a sizable fraction of the total light, which in the general case means unless the actuating effect occupies a substantial portion of the field of view embraced by the photo-cell, the system will require closely adjusted and sensitive relay devices and commensurate maintenance.

It is a feature of a very large majority of photo-electric applications that the object to which they are required to be responsive is, incidentally, a moving object.

It is a matter of common experience that the living eye perceives objects in motion much more readily than it notices stationary things. This is especially apparent to sportsmen and hunters, indeed to any one who is observant of the behavior of those small animals whose longevity varies inversely with the extent to which they are seen by the carnivora. Rabbits, squirrels, chipmunks and all of the smaller fauna, whenever disturbed or alarmed, instinctively "freeze"; so long as they remain immobile they are almost impossible to detect against the landscape or background.

The characteristics of biological vision and reflex action,

which are helpful to such creatures as hawks and owls in securing their quota of nourishment, can usefully be studied and applied by the engineer.

In the photo-electric system which forms the subject of the present paper, a degree of sensitivity, far surpassing that hitherto obtained in systems based on purely quantitative action, is achieved by making the system specifically responsive to the motion of the object.

The reason for the greater perceptibility of a moving animal is that the difference between the still landscape and the movement of a running animal is essentially qualitative. Thus, the enhanced detecting ability of the photo-electric system, now to be described, is due to the fact that the effect which it is employed to detect is a qualitative and not a quantitative change. The system is actuated not by the amount of light falling upon the light-sensitive element, but, instead, in accordance with the first derived function, or rate of change, of illumination. The apparatus is entirely unresponsive to any steady value of illumination, whether of high or low intensity.

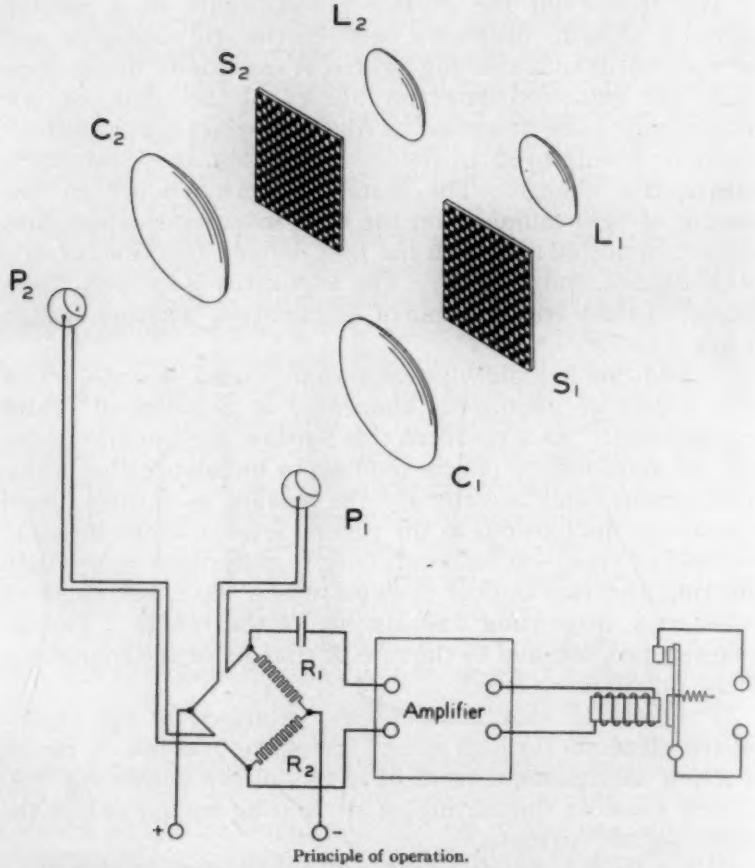
In addition a double optical system is used, in conjunction with a pair of photo-cells connected in a balanced bridge arrangement. As a result of this feature, the apparatus can only be actuated by effects tending to unbalance the bridge arrangement, and accordingly the system is entirely unresponsive to fluctuations in the general level of illumination of the field of view. It responds only to pulsations in the light affecting the two optical systems which have the effect of causing an alternating unbalancing of the bridge. The response is proportional to the rate of change, or the frequency, of the unbalancing effect.

The field of view is, therefore, exhibited to the photo-electric elements through special screens or gratings by means of which continuous movement of any object within the field of view causes a fluctuating or alternating component in the photo-electric currents.

When there is no moving object, no alternating component is present. The movement of the object creates an alternating component. This represents a qualitative change in conditions, which, even though it be of minute amplitude, may be

detected with much greater effective sensitivity than merely a quantitative change. The presence or absence of a characteristic effect can obviously be more readily detected than a

FIG. 1.



Principle of operation.

difference between the magnitudes of two effects of like nature. Thus a much greater degree of amplification can effectively be employed and exceptional sensitivity to small or distant objects is achieved.

Figure 1 shows the essential elements of the system in a diagrammatic form. A pair of objective lenses L_1, L_2 embrace an optical field which includes a movable object which is distinguishable by color or shade from its background; such, as for example, an airplane. Light falling upon the objective lenses is directed through two approximately parallel beams onto the two photo-cells P_1, P_2, shown in the diagram. A pair of condensing lenses C_1, C_2, serve to concentrate the light onto the photo-cells.

The two objective lenses tend to set up duplicate images of the optical field at their respective focal planes. Approximately at these focal planes are mounted two specially divided screens S_1, S_2, through which all the light reaching the photo-cells has to pass.

The two screens are divided into a number of small portions alternately transparent and opaque. The divisions may be regular or irregular and may be according to various shapes or patterns. But both screens are exactly identical in pattern and are of opposite characteristics. That is to say, if any portion of screen S_1 is opaque, the corresponding section of screen S_2 is transparent; and vice versa. In other words, the two screens have exactly the characteristics of a photographic negative and a transparent positive printed therefrom. The screens may conveniently be formed in this manner.

In Fig. 1 these screens are shown divided regularly, according to a checker-board pattern. The rectangular divisions are identical in shape and dimensions. But it will be seen that each square which is transparent in S_1 is opaque in S_2. Likewise, each square which is opaque in one is transparent in the other.

It will be apparent that, according to this arrangement, duplicate images of the field will be cast on the screens. A ray of light emanating from any given point in the field will be projected to duplicate focal points on the screens. But it is important to note, that if the position of the point in the image falls on an opaque section on S_1, the position of the same point on the image formed on S_2, will lie on a transparent section. Thus, the ray of light from the said point will pass through the screen S_2, and will impinge on the photo-sensitive element P_2, whereas the duplicate ray falling on S_1 will be stopped thereby and will not reach P_1.

It follows, therefore, that a ray of light emitted by any given point in the field will be transmitted in duplicate as far as screens S_1, S_2, but thereafter only one of the duplicate beams of light will be further transmitted to the photo-sensitive device, the other one being stopped by the screen. Thus, light from any given point may reach one or other of the photo-sensitive elements. But not, under any circumstances, both of them, at the same time.

Therefore, if an object in the field be mobile, and if it be at such distance from the lenses and of such dimensions that the image thereof, on the screens S_1, S_2, is of the same order of magnitude as the divisions of the screens, or smaller, the image of the object, as the latter moves across the field, will alternately appear on opaque and on tranparent divisions of the screens. When it appears on a transparent portion of S_1 it will stimulate P_1, but will be on an opaque section of S_2 and it will not affect P_2. Likewise, after it has moved a short distance, it will come onto an opaque area on S_1 and onto a transparent portion of S_2 when it will affect the photo-sensitive element P_2 but not P_1. Thus, movement of the object will give rise to alternating stimulation of the photo-cells P_1, P_2.

The frequency of these alternations will depend upon the velocity of movement, the distance of the object from the lenses, and upon the dimensions of the divisions on the screens S_1 and S_2.

If, on the other hand, there be no movement of any kind occurring within the field, no matter what degree of differing color or shade may be distributed, according to any kind of pattern, in the background and other objects comprising the field, the light reaching the photo-sensitive elements P_1, P_2, respectively will be substantially equivalent and of steady value. Variations in the intensity of the general illumination of the field will cause like variation in the stimulus of both P_1 and P_2.

The photo-cells P_1 and P_2 together with two resistors R_1 and R_2 are therefore connected so as to form a balanced bridge circuit, as shown in the Fig. 1. The amplifier is connected, through a coupling condenser, across normally equi-potential points of the bridge.

Thus, only a difference between the amount of light re-

ceived by the two photo-cells P_1 and P_2, will unbalance the bridge. And, because of the condenser coupling, only a varying out-of-balance voltage will affect the amplifier.

The amplifier, therefore, will not respond to changes in the intensity of daylight because this tends to affect both photo-cells simultaneously. This feature is of importance, because, under weather conditions involving cloud effects of the cumulus and similar forms, the passage of cloud patches, of the type which have clearly defined margins, across the face of the sun, may cause the ambient light intensity to undergo a change of several hundred per cent. in a few seconds, representing an appreciable rate of change quite enough to affect, in a substantial degree, a single condenser coupled photo-cell and sensitive amplifier.

A still more important external condition that must not be overlooked is the possible use of apparatus of this type under artificial illumination. The 120 cycle flicker, present in all normal light sources, while it is not apparent to the eye, would affect a single condenser connected photo-cell and amplifier to an extent many times greater than the minimum threshold value of response possible with modern amplifiers.

Both of the above disturbing elements are obviated by the use of the bridge connection.

On the other hand, there are possible circumstances which may make it difficult to secure, or to maintain, an accurate balance of the bridge, and the use of the bridge connection alone would not entirely solve the problem. For instance, some change in the photo-cell characteristics over long periods of time must be contemplated. This will, given sufficient time, cause a permanent unbalancing of the bridge. Again, the field of view, a landscape for example, may change its illumination pattern, due to lengthening shadows and changing incidence of sunlight from hour to hour. If the divisions on the screen are very numerous, such changes will average out. But if the divisions are large enough, these circumstances will cause some slight change over considerable periods of time.

But these changes take place at such a slow rate that an amplifier coupled to the photo-cell, by means of a condenser, is entirely immune to such effects.

The same remarks apply to cloud images, when the apparatus is directed so that the sky, or a portion thereof, comprises the field of view.

In all of these cases the time element is such that the condenser coupling entirely obviates any serious difficulty. The rates of change associated with the generality of free moving objects on the one hand, and in effects of the type enumerated above on the other hand, are so widely different, that a value of capacity, which renders the amplifier responsive to the former, will cause it to be immune to the latter.

The joint effect of both of these features of the system is that it is possible effectively to utilize the maximum degree of sensitivity that the present status of the art of photo-cell and amplifier design renders available. In the generality of previous photo-electric applications, which are actuated by objects, it has not been possible to increase the sensitivity to detect objects at greater distances, or of smaller dimensions, by utilizing more sensitive photo-cells or by employing greater gain in amplification. Such systems have, in the past, been actuated in accordance with the ratio between the photo-electric current variation which is specifically due to the object, and variations due to extraneous light effects. It is this ratio which determines relay settings and limits the effective sensitivity to detect the objects.

Because of the principles embodied in the device, it is possible to utilize in ordinary out-of-door locations, in full daylight, much greater amplification than has hitherto been feasible. In the apparatus described in this paper, an amplifier was installed, having the maximum gain that could be obtained. That is to say, the amplifier was adjusted, with the photo-cells de-energized and closed off from all light, for the greatest degree of sensitivity at which it would remain stable. With this amount of gain the whole equipment, with active photo-cells, remained completely inert in the absence of any visible moving object.

The apparatus has been named "The Petoscope"* in reference to the outstanding quality which it possesses of "seeing" flying objects, in the sense that distinguishes free objects moving in random directions, from objects that move in a predictable manner at pre-determined points.

* Trade mark.

DESCRIPTION OF THE APPARATUS.

Figure 2 shows a general view of the apparatus that has been built for the purpose of studying the possibilities of this new system.

FIG. 2.

The Petoscope. Photo-electric head raised.

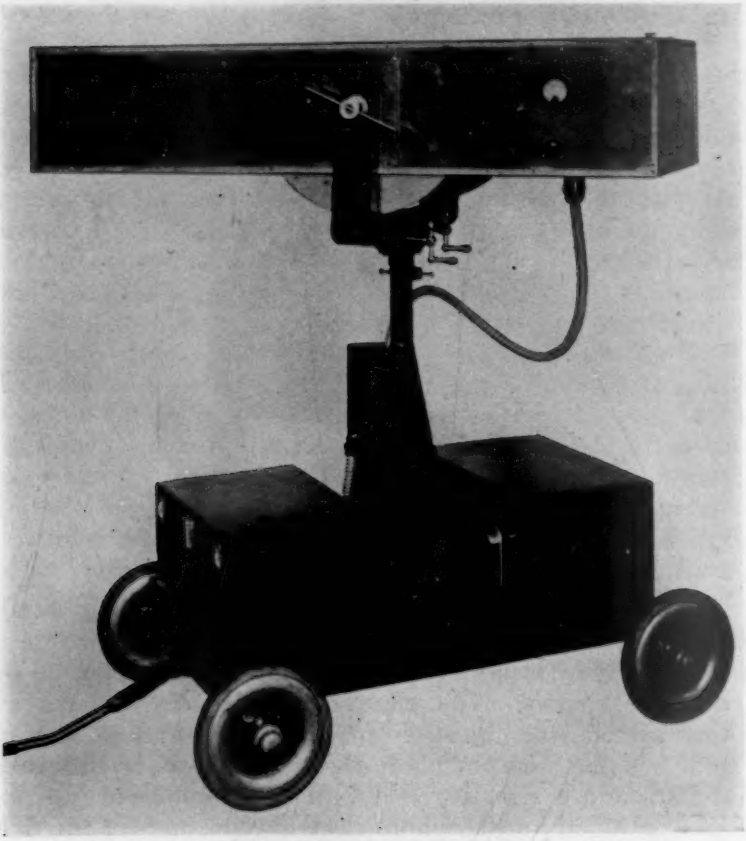
The device comprises the optical, or photo-electric, head, seen in the upper portion of the figure. This, carried in a convenient yoke, is mounted on a central column supported by a movable chassis. The photo-electric head comprises an optical system, the objective lenses of which may be seen in Fig. 2, together with the photo-electric cells, an electron tube amplifier, and a sensitive relay. The optical head also includes batteries for the photo-electric cells, and for the first stage of amplification only. Additional batteries for the re-

maining stages of amplification are carried in the battery box mounted on the rear of the chassis. The front battery box contains two six volt batteries, one of which is employed for heating the cathodes of the amplifier tubes. The other is used for operating various control, relay and signalling apparatus.

As shown in Fig. 2 the optical head can be tilted to any desired angle by means of suitable gearing. It may be rotated about the axis of the center column and may also be elevated.

In Fig. 3 is a view of the apparatus from the other side of the chassis, showing the operating handles for elevation and

FIG. 3.



The Petoscope. Rear view of chassis.

inclination. The nearer handle actuates gearing which, through the segmental racks shown, causes the optical head to be inclined up or down to the desired extent. The farther hand-wheel actuates, through other gearing, a vertical screw within the central column. When this handle is turned the hollow vertical shaft on which the yoke is mounted, may be raised, thus lifting the optical head. This adjustment is convenient when the apparatus is used inside a building upon an upper floor and is aimed through a window at objects outside and below. For such an occasion the optical head would be inclined downwards to a considerable extent, and by means of the elevating arrangement it may be raised so as to clear the window sill. When the optical head has been adjusted to the desired position it may be locked by tightening the clamp screws both on the yoke where the optical head is pivoted horizontally, and on the central column.

In Fig. 3 may also be seen an indicating instrument. Movement of the pointer of this instrument is an indication of the actuation of the device. The knob below the instrument is the sensitivity adjustment.

In Fig. 2 there will be seen in front of the central column, the electrical control arrangements. On the upper portion of the control box are mounted seven switches, three in the upper row and four in the lower row. Reading from left to right, in the upper row the first switch controls the cathode heating circuit, the second switch controls the power relay, and the third switch controls a signal bell. The four lower switches control the anode battery circuits of the amplifier.

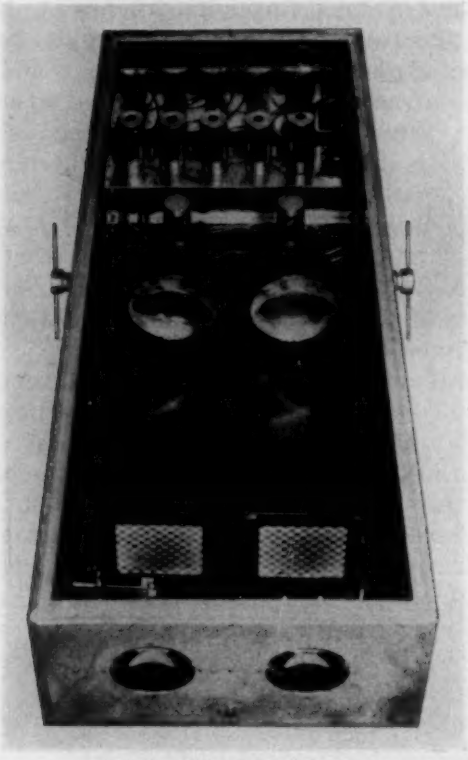
In the weather-proof cast-iron box shown on the central column below the switches is mounted a power or auxiliary relay. When the relay switch, above referred to, is closed, this power relay is operated by the contacts of the sensitive relay mounted with the amplifier in the optical head. In the middle portion of the control box are three outlets, each controlled by a switch. These outlets are energized by the contacts of the power relay, when this is actuated, and are for the purpose of operating additional signal or utility devices in accordance with the photo-electric action of the Petoscope.

In Fig. 3 the signal bell may be seen mounted upon the side of the battery box. In addition, an electric horn is

mounted on the chassis for giving an indication when it is desired to note the action of the device when out of earshot of the bell. When this is required the horn may be plugged into one of the outlets, above referred to, in the center portion of the control box.

Figure 4 shows an internal view of the optical head. At

FIG. 4.



Interior of photo-electric head.

the rear the five-tube amplifier and sensitive relay can clearly be seen. In front are the photo-cells, condensing lenses, screens and objective lenses, all in duplicate.

The two objective lenses are mounted immovably in the front wall of the optical head. Each photo-cell, condenser and screen is, however, mounted upon an individual frame.

Each of these frames are attached to the base of the enclosing structure of the optical head by means of a system of specially formed slots permitting adjustment for focussing upon objects at different distances, like a camera. The front ends of the mounting frames move in two straight slots cut in a direction parallel to the major dimension of the optical head. The rear ends of these frames move in curved slots, these curved slots may be seen in Fig. 4.

The front slots cannot be seen in this figure, but they are visible in Fig. 5, which shows details of the screen mountings to be described later.

The function and purpose of these slots is as follows: In utilizing this device, an image of the field of view is thrown upon the screens. For best results the image should be brought to an approximate focus on the screen at a point corresponding to the distance at which the object is expected to appear.

In the center of the front of the optical head, below the two lenses, in Fig. 4, will be seen a socket, into which a small handle may be inserted when it is desired to adjust the focus. This operates a screw arrangement, which can be seen in Fig. 5, by means of which the two mounting frames bearing the screens, condensing lenses and photo-cells may be both together drawn forward or backward, so that images of the field of view are focussed on the two screens.

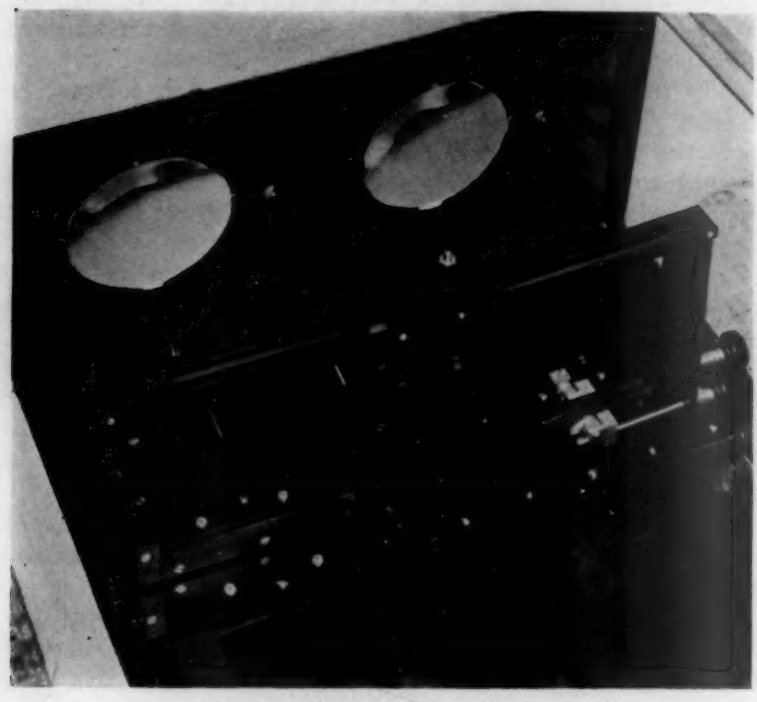
When this is done, because of the curved slots at the rear of the mounting frames, the back portions of the frames are drawn together or spread apart.

Thus, if the screens are focussed on a distant object, corresponding to the "infinity" setting of a camera, the axes of the two optical systems, comprising each, one objective lens, one screen, one condenser and one photo-cell, are substantially parallel.

For focussing on an object which is nearer to the apparatus, the screens would have to be moved backwards. When this is done, by moving each mounting frame bodily towards the rear of the optical head, the front end of the frames, since they are guided by the straight, parallel, back-to-front slots, remain the same distance apart and therefore are still each in line with the fixed objective lenses; but the rear portion of the

frames, being guided by the curved slots, are moved apart as the frames are screwed back. These curved slots are so generated that this spreading movement is exactly the amount necessary to change the two frames from a parallel position to an acute angle which gives the axes of the two optical systems exactly the right amount of "squint" for the less distant object.

FIG. 5.



Screen holders. Details of complementing adjustment.

The screw motion, therefore, gives simultaneous and co-ordinated focus and "squint" adjustment. This feature is due to Mr. George S. Schairer.

The screens are held by the two screen-carriers mounted on the front portions of the two sliding frames. The screens may be inserted in the carriers from the top after the manner of lantern slides.

If the divisions on the screens, in Fig. 4, be carefully inspected it will be seen that they are complementary, that is, a dark or transparent area on one screen corresponds to a light or opaque section on the other screen.

In order to obtain proper "complementing," means are provided for adjusting the relative positions of the two screens. Thus, while the right-hand screen-carrier (referring to Fig. 4) is rigidly mounted, the left-hand screen-carrier can be raised or lowered, or given horizontal movement, by means of the two adjusting screws which may be seen at the side of the left-hand screen holder in Fig. 4.

The construction of the screen-carriers is shown in greater detail in Fig. 5, in which the screens themselves are removed. It will be observed that the nearer of the two adjusting screws, through a worm gear, operates a crank. This crank has a crank-pin engaging a horizontal slot in the screen-carrier, which latter slides vertically in the mounting structure. By operating this screw the adjustable screen can be raised or lowered.

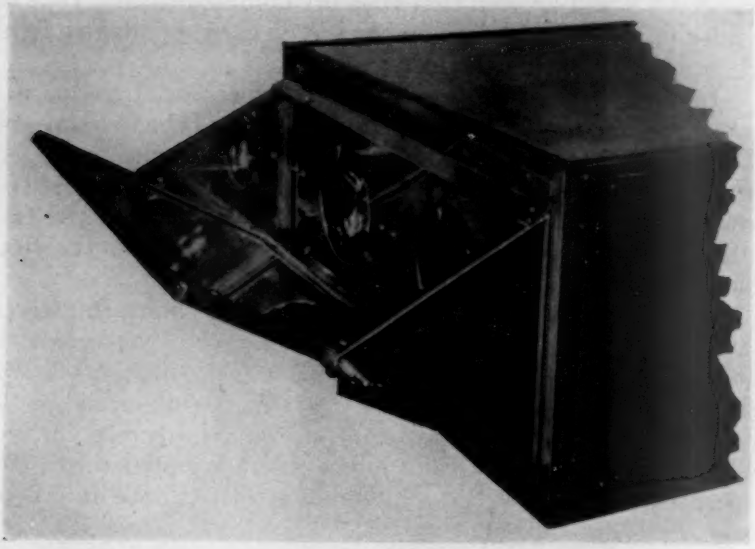
The adjusting screw mounted on the opposite side of the screen-carrier actuates a similar crank, the crank-pin of which, engages a vertical slot in a member which is affixed to a stationary platform carrying the screen-holder. The structure of the screen-holder, however, is mounted upon a sub-base which slides laterally in gibs fixed to the platform. This adjusting screw, therefore, gives cross-motion to the screen.

When both of the adjustments are in mid-position, the two cranks are in quadrature, thus giving the two separate components of motion required.

On referring to Fig. 2, it will be seen that the optical head is provided with a door at right front for access to the complementing adjustment and to enable the image to be inspected when focussing. This door is open in Fig. 5. To facilitate comparison of the duplicate images, while "complementing," two mirrors are mounted in front of the screens. A further door is provided on the right hand side of the optical head (viewed as in Fig. 4) which gives access to the amplifier.

For airplane observation work, or for inspection applications requiring a vertically downward view, instead of providing 90 degree inclination of the optical head a more con-

FIG. 6.



Details of mirror mounting.

FIG. 7.

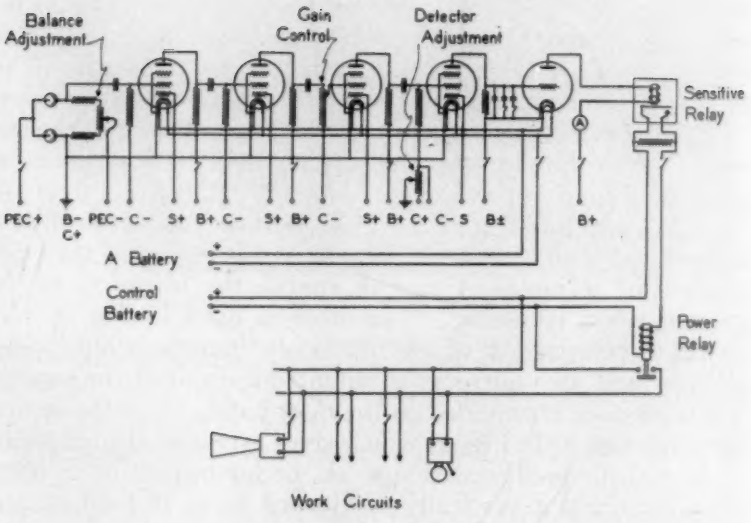


Diagram of connections.

venient adaptation is furnished by means of a mirror which can be attached to the front of the optical head as shown in Fig. 6.

Figure 7 shows a diagram of connections of the Petoscope. The amplifier is of the conventional resistance-capacity type; inter-stage condensers of somewhat greater capacity than is usual in amplifiers for acoustic purposes, are employed on account of the low frequencies involved. As shown in the diagram, four stages of amplification are used, together with a fifth stage comprising a power tube in the anode circuit of which the sensitive relay is included. The fourth tube acts as a detector and is provided with a bias adjustment as shown on the diagram. This is the knob seen in Fig. 3 below the milliameter. The bridge balance adjustment, and gain control, both also indicated in the diagram, are manipulated by the knobs shown on the front of the amplifier chassis in Fig. 4. The sensitive relay can also be noted in Fig. 4 at the right hand end of the amplifier.

Referring again to Fig. 4, in well shielded compartments in back of the amplifier are mounted a battery for the photo-electric cells, a B battery for the first stage of amplification only, and C batteries for all stages. All other batteries are contained in the battery boxes on the chassis. A multi-core cable, carried in a flexible metal hose, as seen in the illustrations, carries all necessary power supplies and connections from the battery boxes and control box to the optical head.

The detector tube in the fourth stage is connected to the power tube in the fifth stage, so as to give trigger action. It will be noted on referring to the diagram that the detector tube plate resistor is directly connected to the grid of the power tube. Under normal circumstances when no signal is picked up by the Petoscope, the detector tube is biased to cut-off. Under this condition the power tube in the last stage carries plate current to the sensitive relay, the armature of which is picked up, holding the contacts of the relay open. When a visual effect actuates the Petoscope, current flows in the plate circuit of the detector tube. This applies a negative voltage to the grid of the power tube, cutting off the plate current and causing the relay to reset and close its contact. The trigger action is adjustable by several condensers connected in parallel

with the plate resistance of the detector. These condensers may be cut in at will by the switches which may be seen in Fig. 4 on the amplifier chassis just in front of the sensitive relay.

The action of these condensers is as follows: With no condenser connected the relay operates and re-sets instantaneously in response to the pulsating photo-electric currents which arise from the action of the screens when an object moves in the field of view of the Petoscope. Without a condenser connected at this point a bell or horn operated by the relay tends to give an intermittent audible signal due to the pulsating effect. When a condenser is used the relay responds instantly to a signal even though the movement made is only an instantaneous one. A momentary flow of current in the plate circuit of the detector tube charges up the condenser. The condenser charge slowly leaks off through the plate resistor. The current of the power tube, therefore, remains cut off, and the relay contact remains closed, until the condenser is discharged. This gives a positive audible signal of finite duration when the Petoscope is instantaneously actuated. The relay contact, of course, remains closed as long as motion of the object persists, the time delay due to the condenser being added after motion has ceased. By means of the condenser switches referred to there may be obtained, at will, either an instantaneous re-set, or audible signals from the bell or horn of several different predetermined durations.

This apparatus was built in the author's laboratory, at Swarthmore College, for the purpose of studying under field conditions, the possibilities of this system of utilizing photo-electric cells. In building this equipment it was aimed to construct something which would be sufficiently practical, rugged, and, reliable for carrying out extensive outdoor test work without unreasonable inconvenience. On the other hand, no effort was made to build a highly efficient optical system. All of the lenses used are of a crude and inexpensive type intended for use as stereopticon condensers. The cost of procuring corrected lenses of large aperture was not considered justifiable for preliminary exploration of the possibilities of this device.

PERFORMANCE.

A series of tests were made with this apparatus at Swarthmore, Pa., and at Patco Airport, Pa.

In order to gain some idea of the distances from the apparatus at which different objects and effects would give reliable and consistent operation, a measured distance was marked out as shown in Fig. 8. As can be seen in the figure

FIG. 8.

Test with automobile at 175 yards.

the first marker is 25 yards from the apparatus, the second is 50 yards, and so forth. The most distant marker is 200 yards away, each intervening 25 yards being indicated.

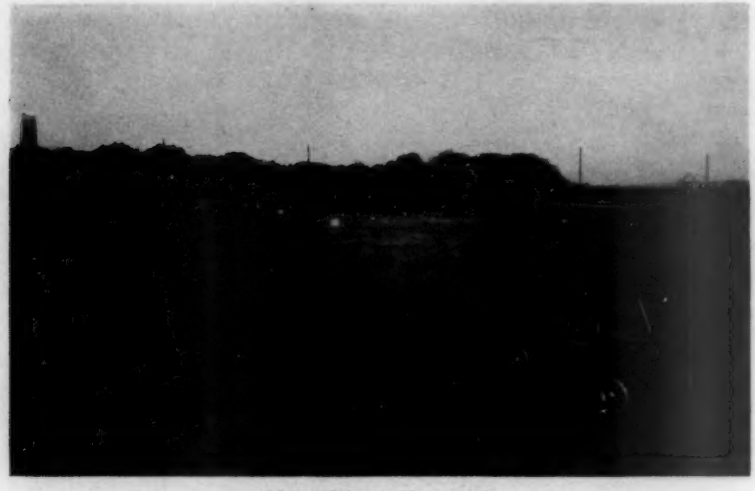
The photographs and tests were made in September towards the end of the afternoon about 4 o'clock Eastern Daylight Saving time. The weather condition was moderately bright sunlight.

A road passes between the 175 yard and 200 yard markers. An automobile was driven up and down this road. This caused operation of the device, the bell or horn being sounded as long as the car remained within the angle embraced by the lenses; this is about 25°. The automobile was a black Ford coupe. Consistent operation of the device with this

automobile was readily obtained. This distance appeared to be about the limit of reliable operation with such an automobile. It will, no doubt be readily understood that had a light colored car been used, even greater distances would have been reached. As shown in the figure, there is little contrast between the automobile and the background.

Figure 9 shows Mr. Bradley C. Algeo, Jr., who assisted

FIG. 9.



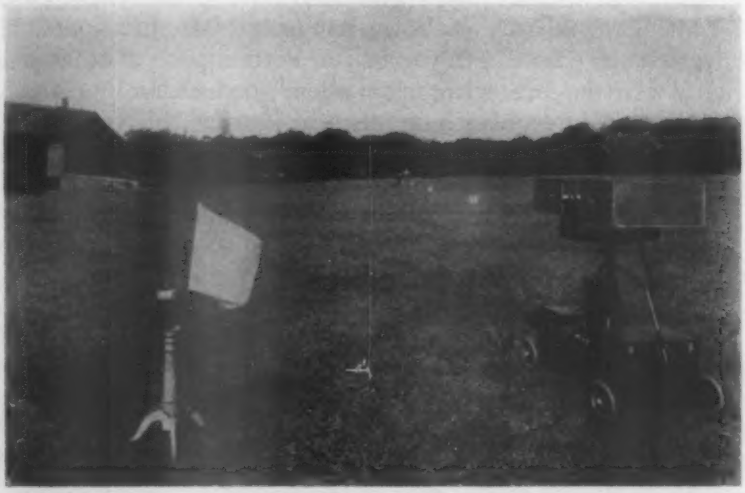
Man walking at fifty yards.

the author in carrying out this work, walking at a distance of 50 yards from the apparatus. This gives consistent operation under the light condition referred to. However, it was found that a person running was readily detected at a distance of 75 yards.

Figure 10 shows a further effect which was demonstrated. To the left of the Petoscope is seen a small motor-operated device arranged to wave a flag whenever the motor is energized. This device is plugged into one of the outlets provided for this purpose in the control box of the Petoscope.

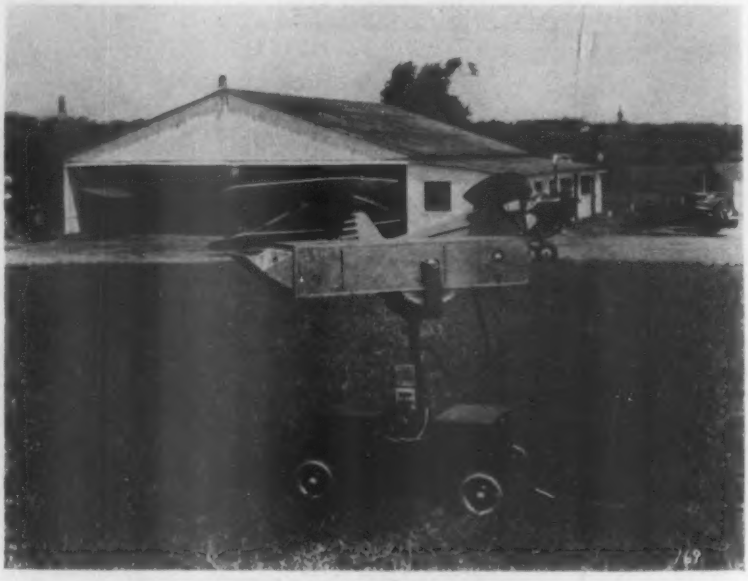
Mr. Algeo with a flag is seen standing between the 75 yard and 100 yard markers. Each time the signaler waves his flag the apparatus, perceiving him, responds with a corresponding flag signal.

FIG. 10.



The Petoscope answering signal flag.

FIG. 11.



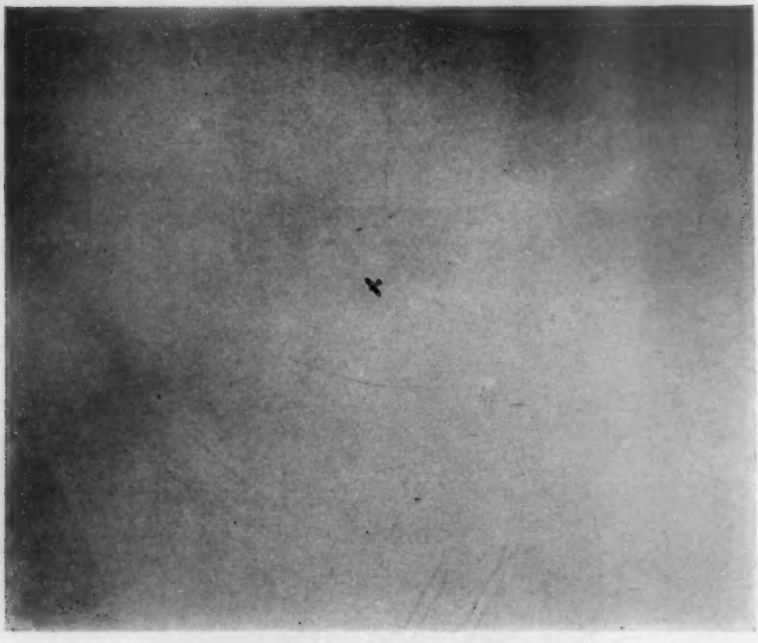
The Petoscope at Patco Field with mirror for vertical view.

Through the courtesy of Messrs. H. A. Little and Lewis Bremer, 3d, further tests were carried out at Patco Field. With the 45° mirror, as shown in Fig. 11, Mr. Little flew his ship so as to pass directly over the Petoscope. A number of flights were made, starting from about 500 feet, and increasing the altitude in regular increments. During this test, which was made in the month of August, around the middle of the day, the sky was overcast and cloudy but with good visibility. There was no direct sunlight at any time. Under these conditions it was found that the Petoscope, adjusted for maximum sensitivity, would respond to the passage of Mr. Little's ship up to an altitude of approximately 2,000 feet.

In order to give a better idea of the significance of these results, instantaneous photographs were taken with a Graflex camera, having a lens of 7″ focal length, and taking a negative 4″ x 5″.

Figure 12 is a reproduction of a photograph taken of Mr.

FIG. 12.



Mr. Little's ship at 2000 feet. Cloudy.

Little's ship as it passed over the Petoscope at a height of 2,000 feet, causing the apparatus to be actuated.

On another day, under better weather conditions of bright sunlight, with considerable background of white fleecy clouds, some further tests were made with the coöperation of Mr. Lewis Bremer, 3d. This time, response was obtained at altitudes up to 3,000 feet. The photograph reproduced in Fig. 13 shows Mr. Bremer's machine on this occasion. Both

FIG. 13.

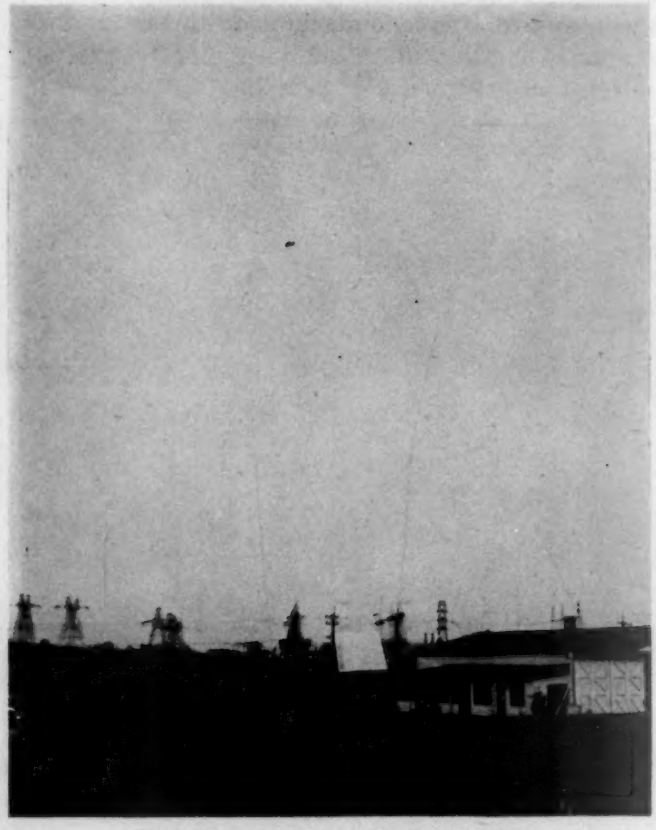
Mr. Bremer's ship at 3000 feet. Clear weather.

Mr. Little and Mr. Bremer fly Lambert Monocoupe ships. Mr. Little's is painted yellow and black, and Mr. Bremer's ship is red in color.

Further tests were made with the 45° mirror removed, and the optical head inclined, the Petoscope being directed at aircraft flying at some distance laterally from the location of the apparatus. Figure 14 is a reproduction of a photograph taken during these later tests. The Petoscope, shown in the foreground, is responding to the passage of Mr. Bremer's ship

flying over Plymouth Meeting substation of the Philadelphia Electric Company. Mr. Bremer's ship is flying at an altitude of more than 1,000 feet, and at a horizontal distance from the Petoscope of at least one-half mile.

FIG. 14.



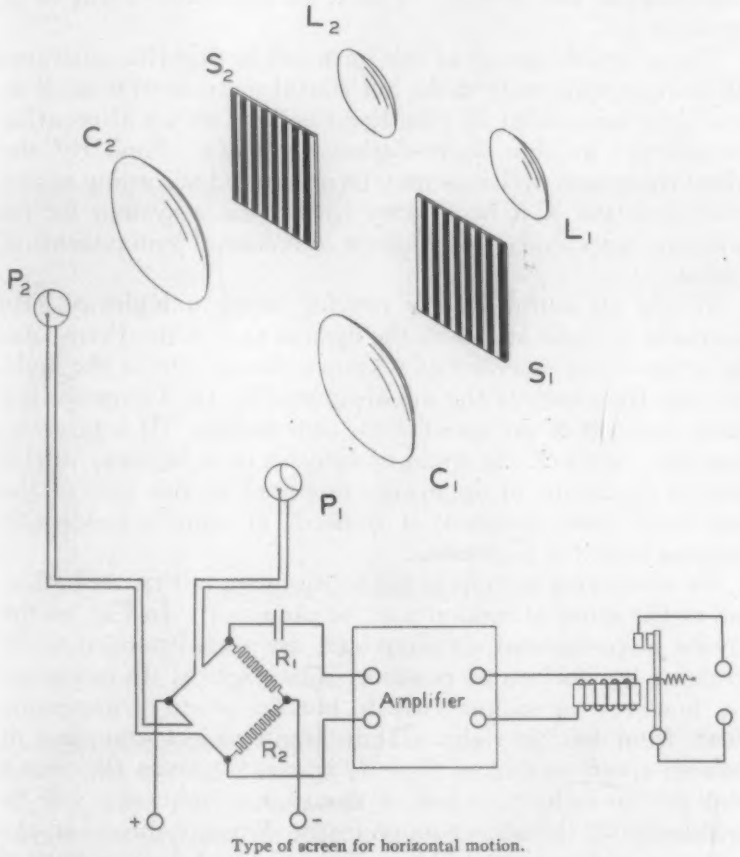
The Petoscope responding to Mr. Bremer's ship.

All of these airplane photographs were taken at the instant of response of the Petoscope to the aircraft, the exposure being made on hearing the sound of the bell.

SPECIAL APPLICATIONS.

In Fig. 1, the screens S_1, and S_2, are shown divided according to a checker-board pattern. This is an appropriate

FIG. 15.



Type of screen for horizontal motion.

arrangement for applications associated with aircraft or any purpose in which the movement of the object may take place in any direction. If, however, the application is such that,

due to the essential nature of the case, the motion of the object takes place entirely, or principally, in one plane only, any other component of the motion being of no significance, it is not necessary to utilize screens S_1, S_2, divided as shown in Fig. 1. For example, in a system primarily intended to be actuated by objects moving across the field of view in a horizontal plane, screens divided vertically only, as shown in Fig. 15, may be used. It is obvious that only the horizontal component of the motion, in such an application, will be of significance.

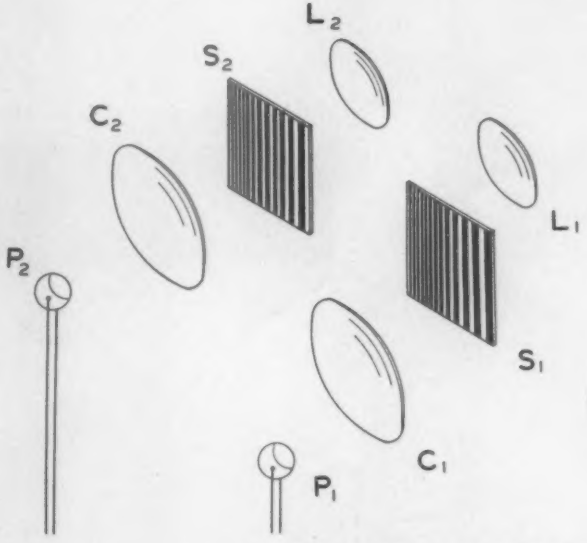
The effect of a screen of this form will be that the apparatus will be responsive only to the horizontal component of motion, since only movement in this direction will set up alternating components in the photo-electric currents. Similarly the axis of the screen divisions may be orientated according to any other direction if it be desired to provide a system for responding selectively to a given directional component of motion.

Where an automobile is moving along a highway substantially at right angles to the optical axis of the Petoscope, the latter being installed at a known distance from the highway, the frequency of the signal emitted by the Petoscope is a direct function of the speed of the automobile. It is possible, therefore, to check the speed of vehicles on a highway in this manner by means of apparatus mounted on one side of the road only, and installed, if desired, at some considerable distance from the highway.

By employing screens of the form shown in Fig. 16, indication of the sense of motion may be obtained. In Fig. 16 the screens have vertical divisions and are thus intended to be actuated by horizontal motion. The vertical divisions are not, however, of uniform width, but are made of increasing width from left to right. Thus, if an object traveling at uniform speed moves so that its image traverses the screen from left to right, a signal of decreasing frequency will be furnished. If the object move in the opposite direction, the frequency will increase. Thus, if these signals be transmitted or registered in any suitable manner, an indication or record of the sense of the motion of the object may be obtained. For example, if this signal be listened to on a telephone, it

will have a clearly defined characteristic sound in accordance with the sense of movement. Alternatively, the signal may be recorded on an oscillograph or string galvanometer.

FIG. 16.



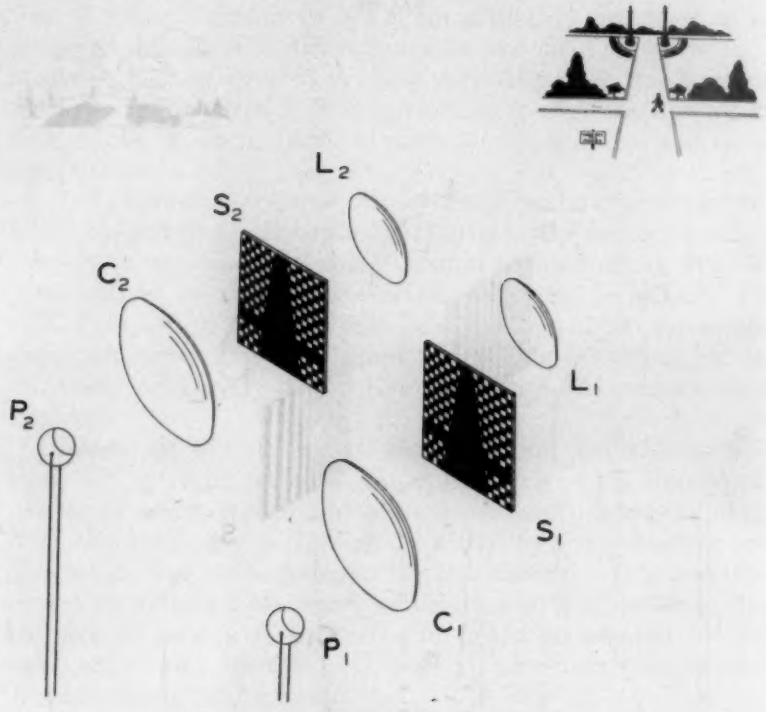
Type of screen for indicating direction of motion.

As is suggested in Fig. 16, this principle has obvious possibilities in connection with military and naval reconnaisance.

Another example of the use of screens of special design for obtaining specially selective response characteristics is shown in Fig. 17. Such an arrangement is capable of indicating whenever persons, or other movable objects, traveling across a field of view, deviate from a predetermined path or intrude into an undesired area. As shown in Fig. 17, this effect is obtained by blacking out duplicate portions of the screens S_1, S_2, corresponding to the image of the area within which

movement is to be permitted. For example, in the park scene shown in Fig. 17, the area corresponding to the driveways is

FIG. 17.



Selective action. Portions of screen opaqued.

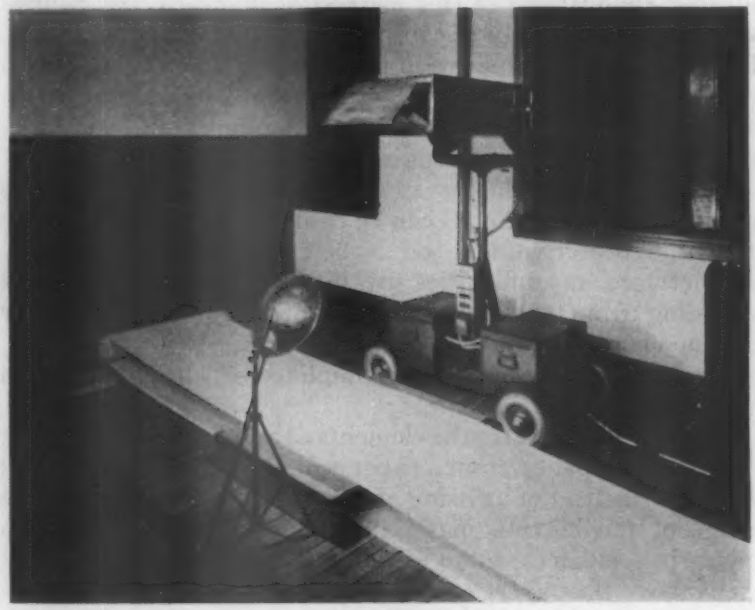
completely opaqued in both of the screens and no response will be made by the Petoscope to any person moving on the driveway so that his image falls upon the blind area. Should any one stray on to the flower beds or grass, the image would appear upon checker-board sections of the screen and the Petoscope would be actuated.

In addition to the typical arrangements described above in connection with open air applications relating to free-moving objects at a considerable distance from the photo-electric apparatus, the Petoscope principle is specially applicable to problems in connection with manufacturing and industrial

processes where it is desired to employ photo-electric methods for the inspection of materials.

Such applications are mainly concerned with material which is handled in continuous webs, strips or sheets, such as, for example, in the paper making, textile and tin plate industries, or in painting, cleaning or dyeing operations.

FIG. 18.



Set-up for detecting blemishes on paper.

Figure 18 illustrates a test set-up utilizing the apparatus already described in connection with the several outdoor tests. For this purpose the 45° mirror was used, so as to cause the Petoscope to survey, in a vertical downward direction, material passed before it. A band of paper 30″ wide, by means of rollers, one of which may be seen in Fig. 18, was caused to travel past the Petoscope at a speed of several hundred feet per minute. A dark mark, the size of a fifty cent piece was affixed to the paper at different distances from the edge. The paper, at the point where it came into the field

of view of the Petoscope, was illuminated by means of a photographic studio lamp.

It was found that under these conditions the Petoscope readily responded each time the dark mark, representing a blemish or defect, passed across its field of view.

This arrangement, however, is probably not the simplest or most effective set-up for material inspection. In the tests illustrated in Fig. 18, the type of apparatus designed for the outdoor applications of this method of photo-electric control was employed merely because it happened to be available. The conditions of application in a material inspection system are quite different from the circumstances encountered in connection with such objects as automobiles and airplanes and, in general, the problem is much more simple.

For example, in the case of an inspection system, it may be assumed that the material can be exhibited at a fixed distance from the objective lens on a belt conveyor or the like. Furthermore, no difficulties are likely to be encountered in excluding from the field of view of the Petoscope other extraneous moving objects or light effects.

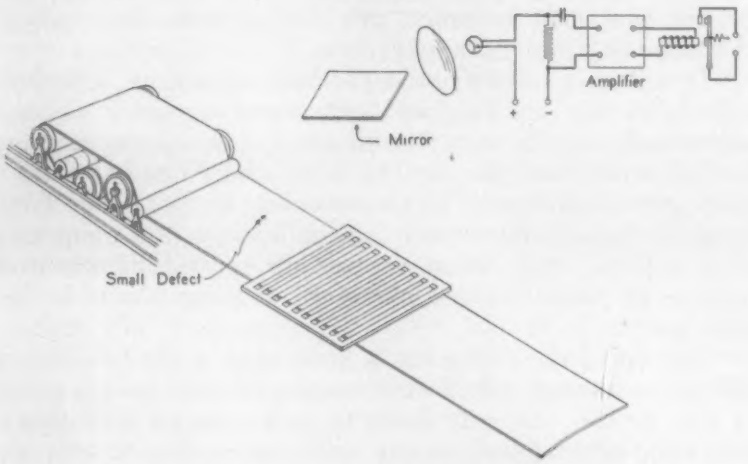
For such arrangements the simplified set-up illustrated in Fig. 19 is more appropriate.

Figure 19 illustrates the elements of a suitable arrangement for inspecting paper, from a paper mill, for small blemishes and defects. Instead of utilizing an objective lens and forming an image of the moving material upon divided screens, as in Fig. 1, it is much easier to install a screen or grating immediately above the paper. Since the paper can only move in one direction, a simple screen in the form of transverse slats is all that is necessary. There is no point in the use of a checkerboard arrangement. This construction is not only less expensive in that it avoids the necessity of providing objective lenses, but is, in fact, more efficient. This is because of the more perfect obturation given by such a screen when the actual blemish passes behind the slats. In an arrangement, such as is shown in Fig. 1, the effectiveness of the obturating action depends very much on the quality of the objective lenses L_1, L_2, which are used. With lenses of large aperture there is always a certain amount of glare and diffusion which tends to vitiate the effectiveness of the apparatus.

In Fig. 19 a single lens is all that is necessary to gather into the photo-cell light from the area inspected. A mirror is shown in Fig. 19, the axis of the photo-electric device being horizontal. This may, of course, be omitted if it is convenient to mount the photo-cell vertically above the track of the paper.

With this arrangement, of course, it is necessary that the area of paper which is embraced by the photo-electric system,

FIG. 19.



Simplified arrangement for material inspection system.

be illuminated with light of a steady and uniform value. It would not be feasible to employ an alternating current source of illumination. Direct current must be used and this should be regulated so as to avoid any sudden or abrupt changes in light intensity. It is not important that the direct current source from which the light is energized, be maintained at an exact value, so long as any changes which take place occur sufficiently slowly to avoid incorrect operation of the amplifier.

The sensitivity of this arrangement can be materially increased if it is convenient, as it probably would be in practice, to run the paper at a fixed and predetermined speed. If this can be done, the pulsations which are set up as the result of the presence in the paper of a small defect, will

always be of the same characteristic frequency. By using a tuned amplifier or relay, resonant to this frequency, the efficiency of the system will be greatly enhanced.

CONCLUSIONS.

The major purpose of the present paper has been to describe the working principles and constructional features of the apparatus built by the author. The performance and tests described are intended merely to give some idea of the order of sensitivity which can be obtained and to suggest some of the directions in which this development may enlarge the scope of photo-cell applications.

It will be specially noted that the apparatus is entirely self-contained, requiring no light source or other external appurtenances. It may be directed upon or toward any desired scene with the facility with which one may use a photographic camera. This outstanding feature of the Petoscope is of great importance for applications of a temporary or peripatetic type, where the setting up and alignment of light-beam projectors and photo-cell housings would be impracticable.

The use of the Petoscope in connection with the flight of aircraft, represents a field which emphasizes the unique action of this device. Aircraft in flight, as compared with pedestrians and automobiles, are not readily susceptible to detection by the interception of a definite beam of light; first, because of the difficulty of providing a light source and photo-cells on opposite sides of an airplane; and second, because aircraft do not follow predetermined paths, such as highways.

The apparatus described and illustrated herein, represents the first practical field equipment. The results obtained and described in connection with the photographs of the tests may significantly be interpreted in the light of the following considerations.

The amplifier and electrical arrangements employed are probably not susceptible of any great degree of improvement so far as sensitivity is concerned. The major limitations encountered in building, adjusting, and making use of the amplifier and signal arrangements described, were found to be associated with "feed-back" or "pick-up" arising from

the action of the power relay, the bell, horn, and other work-devices actuated when the Petoscope responds to a visual effect. Careful adjustment of the resistance connected in parallel with the contacts of the sensitive relay, shown in the diagram of connections, was found to be very necessary. Part of the "pick-up" was clearly mechanical and microphonic, especially when the electric horn was in use. Removal of the horn from the chassis of the Petoscope enabled an increase in the net sensitivity to be obtained. The remainder of the "pick-up" effect appeared to be electromagnetic, rather than to arise from sparking of relay contacts. For example, two different types of power relay were employed, one of which had a smaller air gap and a more efficient magnetic circuit than the other. The former, therefore, might be expected to set up inductive effects of greater intensity than the latter. The "pick-up" effects encountered when utilizing the first mentioned power relay were notably greater; and substantially better over-all sensitivity was obtained with the less efficient type of relay.

The several tests indicating the effective distances at which the Petoscope responded to the various objects, represent the extreme limit at which repeated and consistent operation could be obtained with the apparatus carefully adjusted for optimum performance.

On the other hand, the optical arrangements are not, by any means, commensurate with the electrical equipment. The provision of a carefully planned and constructed optical system was at first contemplated. For preliminary exploration an inexpensive refracting system was installed. The performance furnished by the Petoscope with these primitive optical arrangements, appeared to be sufficiently striking to warrant the carrying out of field tests with this equipment. This decision was further influenced by the fact that, while the four lenses used in this model of the Petoscope were obtained at a cost of less than $15.00, inquiry showed that no properly corrected lenses of equivalent or greater dimensions were obtainable except at a cost of several hundred dollars.

These uncorrected lenses, while giving clear definition of the image upon the screen, set up a "glare" or "diffusion" effect which has the apparent result, when the image on the

screen is observed, of greatly reducing the contrast. For example, if a small dead black spot on a clear white background be exhibited to the Petoscope, the image on the screen will consist of a much less dark spot in relation to the background than the appearance of the object itself. Just how much this type of aberration has limited the results obtained, is not, at present, known, and can only be determined by further tests with properly corrected lenses.

It should, in this connection, be pointed out that the quantitative relations in this or any similar photo-electric applications, are such that the magnitude of the photo-electric effect set up when any given field of view is exhibited to the Petoscope, is directly proportional to the "aperture," utilizing this latter word in the sense in which it is used in photography. "Stopping down" for definition, as would be done to improve photographic quality, merely reduces the photo-electric effect, and cuts down the sensitivity of the Petoscope. The type of lens required for this device is similar to the requirements of high speed photography. In other words, for lenses of a given focal length, the sensitivity of the Petoscope tends to be proportional to the square of the effective diameter of the objective lens.

From these considerations, it will, therefore, be clear that the performance indicated in the tests described can be greatly extended by the provision of a more perfect refracting system. Apparatus of the Petoscope type, equipped with corrected lenses of substantially increased diameter along the lines of astronomical instruments can definitely be expected to achieve a sensitivity substantially surpassing the results described in the present paper, in direct proportion to the improvement in the optical arrangements.

Some definition of the use of the word "sensitivity" in this discussion of the performance of the Petoscope may be in point.

Under given light conditions, and with a moving object of given visibility—by which is meant an object having a given degree of color contrast to the field in which it moves, considered in relation to the color response of the photo-electric cell employed—the basic sensitivity of the Petoscope is proportional to the area of the field of view effectively em-

braced, divided by the area of the object. In other words, an increase in the sensitivity of the apparatus will make possible the detection of smaller objects in a field of given dimensions, or will enable detection of a given object when a larger field is covered by the apparatus.

The effective sensitivity, of course, of the performance of the Petoscope, in detecting small objects, is increased in direct proportion to the intensity of the prevailing illumination. The sensitivity is further proportional to the speed of motion of the object.

These considerations of basic sensitivity relate more particularly to applications of the type referred to in connection with Figs. 18 and 19. The effective sensitivity possible in open air applications in connection with highway traffic and pedestrian movement, etc. depends upon the prevailing conditions and the extent to which non-relevant motion effects may be avoided. For example, in mounting a Petoscope for applications of this type, if it be desired to realize the full sensitivity of which the apparatus is capable, it is advisable to avoid, in the foreground, trees or other objects liable to be set in motion by the wind. However, where a particular branch, for example, gives rise to this limitation, the difficulty may often be avoided, if the motion effect, to which the device is required to respond, is below or away from the offending branch, by opaquing the screens at the point where the image of the branch occurs, as in Fig. 17.

Similarly, if action is desired in response to very distant objects, it is advisable to mount the apparatus in an enclosure having a suitable window so as to prevent the approach of birds or insects sufficiently near to the objective lenses to actuate the device.

ACKNOWLEDGMENT.

In conclusion, the author wishes respectfully to acknowledge his great indebtedness to the late Dr. Lewis Fussell, and to thank President Aydelotte, the Faculty of the Division of Engineering, and the Board of Managers, of Swarthmore College, for making available to him the facilities which have made possible the work which forms the subject of this paper.

Pumping Station Walls Damp-Proofed by Use of Pressure Creosoted Lumber.—(*Wood Preserving News*, Vol. XIV, No. 4.) The city of Baltimore is now completing work on the construction of the Ashburton Pumping Station, an important new unit in its water supply system. This is a building 100 × 71 ft. of stone construction on concrete foundation. An ingenious arrangement of the machinery pits results in compact layout accommodating four pumping units, two of which are 18 million gals. each per day, and two 12 million gals. each per day. As is typical of pumping plants, about as much of the building is below ground surface as above. In fact the lower floor of the machinery pits is approximately 20 ft. below grade and the water level, though fluctuating very considerably, rises intermittently to a point relatively close to the ground surface. At the ground surface, surrounding the whole area a 1½ × 2 in. pressure creosoted strip of clear cypress is embedded in the masonry walls, its face flush with the outer surface, the anchoring with copper nails extending into the concrete. Pressure creosoted 1 × 6 in. boards, tightly nailed up to 2 × 6 in. studs, forming wall plates, were then placed in contact, the plate side to a 5 ply membrane waterproofing around the outside of the walls. On the assembled wall plates a second sheathing, similar to the first is nailed leaving a 6 in. space between the two lines of sheathing. On a 3 in. slab at the bottom, opposite the wall footings is laid a 6 in. tile drain, after which the space provided by the 6 in. studs is filled with gravel. The drain leads to a sump in the building. After an unusually wet season, the walls and floor have remained in a perfectly dry condition.

R. H. O.

ON THE ANOMALOUS PROPERTIES OF DIELECTRICS.

BY

JACOB NEUFELD,

Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, Pa.

SUMMARY.

The causes of energy losses in dielectrics subjected to alternating stress are not completely understood. One of the most satisfactory methods of treating these problems, due to von Schweidler, attributes the dielectric loss entirely to dielectric absorption. Some agreement between the methods of von Schweidler and experimental data has been found by F. Tank, J. B. Whitehead and R. R. Benedict. However there does not exist a satisfactory test of the accuracy of the analysis of von Schweidler. The present paper gives:

(1) a method of separating the losses due to hysteresis from the losses due to absorption in dielectrics,

(2) a method for determining analytically the absorption curve of a dielectric in which hysteresis is absent,

(3) a graphical method of checking the accuracy of von Schweidler's analysis.

INTRODUCTION.

It was shown by W. von Siemens in 1864 [1] that a dielectric submitted to an alternating stress develops a considerable amount of thermal energy to which the name "Siemens heat" was given. His investigation was followed by many others [2] and the "Siemens heat" was often attributed to the following causes:

1. The anomalous charging, or absorption current.
2. The dielectric hysteresis.

The anomalous charging or absorption current of a condenser may be defined to be the current given by a curve which shows the difference between the instantaneous values of the charging current which actually flows under a steady charging emf and the corresponding value of the current as

[1] *Pogg. Ann.*, 125, p. 137, 1864.

[2] For a bibliography see for instance J. B. Whitehead, "Lectures on Dielectric Theory and Insulation," McGraw-Hill Book Co., New York, 1927.

computed by the classical theory assuming a constant value of capacitance and leakage conductance.

The term "dielectric hysteresis" which has been used in connection with various investigations of dielectrics, and which will be used here, has a very special significance. The conventional view is to the effect that the hysteresis phenomena are directly reflected in the charging current as a function of time and consequently manifest themselves in the absorption current. Our purpose here is to admit tentatively another contribution not contained in the absorption current which is not a consequence of so-called "hereditary action" due to which the state of a material would depend upon its past history. This additional contribution is denoted as the result of the action of "dielectric hysteresis."

The earlier investigators assumed that the dielectric losses were due to hysteresis. Many experimental facts have shown however, that this assumption is untenable and various investigators who have attacked this problem attributed the cause of dielectric loss to the anomalous charging current. Von Schweidler [3] has calculated the dielectric loss which should be observed in an alternating field in a dielectric which is characterized by a given absorption current. Some agreement between the values obtained from von Schweidler's expressions and the measured values was obtained by F. Tank,[4] J. B. Whitehead [5] and R. R. Benedict.[6] However no satisfactory test of the accuracy of von Schweidler's analysis exists at present.

The object of the present investigation is:

(1) to give a method which will permit the separation of dielectric losses due to absorption from losses due to hysteresis;
(2) to give a graphical method of verification of von Schweidler's analysis;
(3) to determine an empirical expression for the absorption current of a dielectric which can be handled by the method of von Schweidler, i.e. by neglecting hysteresis.

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[3] *Ann. d. Phys.*, **24**, 1907, p. 711.
[4] *Ann. d. Phys.*, **48**, 1915, p. 307.
[5] JOURN. OF FRANKLIN INST., **208**, 1929, p. 453.
[6] *Transactions of the A.I.E.E.*, **49**, 1930, p. 739.

1. SEPARATION OF THE HYSTERESIS LOSSES FROM THE ABSORPTION LOSSES.

Consider a dielectric submitted to a voltage $E \sin \omega t$ and let the corresponding current be $I(t)$. It is understood that $I(t)$ as well as the absorption current $\varphi(t)$ may be perfectly determined for a given dielectric and both of the corresponding curves can be experimentally recorded. We have:

$$I(t) = I_1(t) + I_r(t) + I_a(t) + I_h(t), \tag{1}$$

where $I_1(t)$ is the current due to the geometrical capacity of the dielectric:

$$I_1(t) = \omega CE \cos \omega t, \tag{2}$$

$I_r(t)$ is the normal conduction current through the dielectric

$$I_r(t) = \frac{E}{R} \sin \omega t, \tag{3}$$

$I_a(t)$ is the current due to absorption and $I_r(t)$ is the current due to the presence of hysteresis.

By applying the principle of superposition we can express the current in the following form:

$$I_a = E(0)\varphi(t) + \int_0^t \frac{dE}{d\lambda} \varphi(t - \lambda) d\lambda. \tag{4}$$

Substituting $E(t) = E \sin \omega t$ we have:

$$I_a = \omega E \int_0^t \cos \omega\lambda \varphi(t - \lambda) d\lambda. \tag{5}$$

Using Borel's theorem we shall express this relation in operational notation.[7] Taking

$$\int_0^\infty \cos \omega\lambda \epsilon^{-p\lambda} d\lambda = \frac{p}{p^2 + \omega^2}, \tag{6}$$

$$\int_0^\infty \varphi(\lambda) \epsilon^{-p\lambda} d\lambda = \frac{f(p)}{p}, \tag{7}$$

$$\int_0^\infty I_a(\lambda) \epsilon^{-p\lambda} d\lambda = \frac{F(p)}{p}, \tag{8}$$

[7] V. Bush, "Operational Circuit Analysis," John Wiley & Sons, New York.

we have

$$F(p) = \frac{\omega E p f(p)}{p^2 + \omega^2}. \tag{9}$$

The function $I_a(t)$ can be expressed in the form of a contour integral in the complex plane

$$I_a(t) = \frac{\omega E}{2\pi i}\int_{c-i\infty}^{c+i\infty} \frac{pf(p)}{p^2+\omega^2}\frac{\epsilon^{pt}}{p}dp \quad \text{where } c > 0. \tag{10}$$

Since $I_a(t)$ does not possess any d.c. component, the function under the integrand is regular at the origin and consequently we can write

$$I_a(t) = \frac{\omega E}{2\pi i}\int_{-i\infty}^{i\infty} \frac{f(p)\epsilon^{pt}}{p^2+\omega^2}dp. \tag{11}$$

Changing the variable from p to $u = -ip$ we obtain

$$I_a(t) = \frac{\omega E}{2\pi}\int_{-\infty}^{\infty} \frac{f(iu)}{\omega^2 - u^2}\epsilon^{iut}du. \tag{12}$$

Now let

$$f(iu) = C(u) + iD(u). \tag{13}$$

Then

$$\begin{aligned}\int_{-\infty}^{\infty} &\frac{f(iu)}{\omega^2-u^2}\epsilon^{iut}du \\ &= \int_{-\infty}^{\infty} \frac{[C(u)+iD(u)][\cos ut + i\sin ut]}{\omega^2-u^2}du \\ &= \int_{-\infty}^{\infty} \frac{1}{\omega^2-u^2}[C(u)\cos ut - D(u)\sin ut]du \\ &+ i\int_{-\infty}^{\infty} \frac{1}{\omega^2-u^2}[C(u)\sin ut + D(u)\cos ut]du. \end{aligned} \tag{14}$$

Since $I_a(t)$ is real the second integral in (14) vanishes so that $I_a(t)$ is reduced to the real part:

$$I_a(t) = \frac{\omega E}{2\pi}\int_{-\infty}^{\infty} \frac{1}{\omega^2-u^2}[C(u)\cos ut - D(u)\sin ut]du. \tag{15}$$

Since $I_a(t)$ is zero for the negative values of t we shall have, substituting $-t$ for t,

$$0 = \frac{\omega E}{2\pi}\int_{-\infty}^{\infty}\frac{1}{\omega^2 - u^2}[C(u)\cos ut + D(u)\sin ut]du, \quad (16)$$

and from (15)

$$I_a = \frac{\omega E}{\pi}\int_{-\infty}^{\infty}\frac{C(u)}{\omega^2 - u^2}\cos utdu. \quad (17)$$

The imaginary term in the expression (14) vanishes for both positive and negative values of t. Consequently the following relation has to be satisfied:

$$\int_{-\infty}^{\infty}\frac{C(u)}{\omega^2 - u^2}\sin utdu = \int_{-\infty}^{\infty}\frac{D(u)}{\omega^2 - u^2}\cos utdu = 0.$$

Now, the functions $C(u)$ and $D(u)$ can be easily determined graphically. Since $\varphi(\lambda)$ is a decaying function which reaches the value zero after a certain period of time k, we can write, according to (13),

$$\int_0^k \varphi(\lambda)\epsilon^{-iu\lambda}d\lambda = C(u) + iD(u), \quad (18)$$

from which

$$C(u) = \int_0^k \varphi(\lambda)\cos u\lambda d\lambda, \quad (19)$$

$$D(u) = \int_0^k \varphi(\lambda)\sin u\lambda d\lambda. \quad (20)$$

With the use of the harmonic analyzer we can determine $C(u)$ and $D(u)$ for any value of u and consequently we can reproduce graphically the functions

$$\frac{C(u)}{\omega^2 - u^2} \quad \text{and} \quad \frac{D(u)}{\omega^2 - u^2}$$

between any desired limits.

Consider now the expressions

$$I_a'(t) = \frac{\omega E}{\pi}\int_{-M}^{M}\frac{C(u)}{\omega^2 - u^2}\cos utdu \quad (21)$$

and

$$\rho'(t) = \int_{-M}^{M}\frac{C(u)}{\omega^2 - u^2}\sin utdu, \quad (22)$$

M being a positive real number.

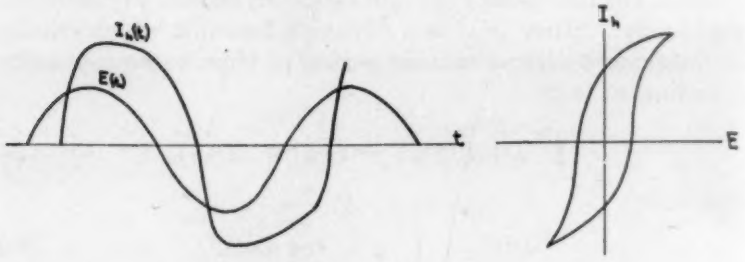
With the use of the harmonic analyzer we can reproduce the function $I_a'(t)$ graphically as well as $\rho'(t)$. We know that $I_a'(t)$ is an approximation to $I_a(t)$ which is generally closer if the value of M is greater. As $\lim_{M\to\infty} \rho' = 0$ the magnitude of ρ' for a given value of M gives an indication of the degree of approximation obtained.

The "hysteresis current" can now be obtained from the relation

$$I_h(t) = I(t) - I_1(t) - I_r(t) - I_a(t). \tag{23}$$

Let Fig. 1 represent graphically the curve $I_h(t)$ and the

FIG. 1.



corresponding variation of $E(t)$. From these two curves we can construct the hysteresis loop for a given dielectric.

2. VERIFICATION OF VON SCHWEIDLER'S THEORY.

Various experimental investigations have shown that in a great many dielectrics the hysteresis action is very insignificant. The method due to von Schweidler neglects it entirely. By the principle of superposition we have

$$i(t) = C\int_{-\infty}^{t} \frac{dE(\tau)}{d\tau}\varphi(t-\tau)d\tau, \tag{24}$$

where C is the geometric capacitance and $E(t)$ the variation of voltage and $\varphi(t)$ is the absorption current.

If we replace $t - \tau$ by u we obtain

$$i = C\int_{0}^{\infty} \frac{dE(t-u)}{du}\varphi(u)du. \tag{25}$$

Assuming that the voltage varies sinusoidally and substituting in this equation $E \sin \omega t$ for $E(t)$ we obtain:

$$i(t) = \omega CE\left[\cos \omega t \int_0^\infty \phi(u) \cos \omega u du + \sin \omega t \int_0^\infty \phi(u) \sin \omega u du\right]. \quad (26)$$

Let

$$A \equiv \int_0^\infty \varphi(u) \cos \omega u du \quad (27)$$

and

$$B \equiv \int_0^\infty \varphi(u) \sin \omega u du; \quad (28)$$

then

$$i(t) = \omega CE[A \cos \omega t + B \sin \omega t]. \quad (29)$$

Taking into account the leakage resistance R and the geometric capacity C the total current passing through the condenser will be

$$I(t) = \omega CE\left\{(1 + A) \cos \omega t + \left(\frac{1}{\omega CR} + B\right) \sin \omega t\right\}. \quad (30)$$

If the leakage conductance is neglected the loss will be given by

$$W = \tfrac{1}{2}\omega CE^2 B. \quad (31)$$

The apparent capacity is

$$C' = C + A. \quad (32)$$

We can measure the values W and C' from the equations (31) and (32) to derive the corresponding values for A and B. If it were possible to calculate A and B from the formulas (28) and (29) and compare with values from (31) and (32), there would be given an indication of the validity of the method. Unfortunately, however, it has been found difficult to give an empirical formula which would represent $\varphi(t)$ with close accuracy and which would permit the evaluation of A and B. Some work along these lines has been done by the previously mentioned investigators, namely, F. Tank,[5] J. B. Whitehead[6] and R. R. Benedict.[7] However, owing to the simple form assumed for $\varphi(t)$, these investigations may hardly be considered a confirmation of von Schweidler's theory.

The main difficulty in verifying von Schweidler's theory consists in computing the quantities

$$A \equiv \int_0^\infty \varphi(u) \cos \omega u du,$$

$$B \equiv \int_0^\infty \varphi(u) \sin \omega u du,$$

in cases in which the function $\varphi(u)$ cannot be expressed by a simple formula such as those proposed by various investigators. There seem however to be no difficulty in evaluating with the harmonic analyzer exactly the same quantities

$$\int_0^k \varphi(u) \cos \omega u du, \tag{33}$$

$$\int_0^k \varphi(u) \sin \omega u du. \tag{34}$$

Moreover the quantities A and B can be computed for various frequencies in order to see whether the variation of the apparent capacitance

$$C' = C(1 + A),$$

and of the dielectric loss

$$W = \tfrac{1}{2}\omega C E^2 B$$

with the frequency agree with the experimental results.

3. EMPIRICAL FORMULA FOR AN ABSORPTION CURRENT.

Various attempts have been made to find an empirical formula which would express with close accuracy the absorption current. The most important of the formulas proposed are as follows:

$$\varphi(t) = at^{-m}, \tag{35}$$

$$\varphi(t) = a\epsilon^{-bt^n}, \tag{36}$$

$$\varphi(t) = \frac{a}{1 + bt}, \tag{37}$$

$$\varphi(t) = \frac{a}{b + t} + c, \tag{38}$$

$$\varphi(t) = a\epsilon^{-bt} + c. \tag{39}$$

None of these formulas fits the corresponding curve with close accuracy. However it has been observed by several observers (Hopkinson, von Schweidler, Wagner, Steinmetz) that by using several terms of the equation (36) each with $n = 1$ but with different constants, we can approximate the curve as close as desired. Whitehead and Banos have shown that only few terms have to be taken into account.[8]

In that which follows there will be shown a method of determining with close accuracy the absorption current for those dielectrics to which the von Schweidler's theory is applicable. (This can be verified by the method shown above.) Since in all the dielectrics the hysteresis action is insignificant, we can neglect the term $I_h(t)$ in the equation (1) and consequently can write

$$I(t) = \omega EC \cos \omega t + \frac{E}{R} \sin \omega t + I_a. \tag{40}$$

Let

$$I(t) = A_1 \sin \omega t + A_2 \sin 2\omega t + \cdots + B_1 \cos \omega t + B_2 \cos 2\omega t + \cdots, \tag{41}$$

where $A_1, A_2, \cdots B_1, B_2, \cdots$ are Fourier's constants which can be determined for a given curve. We can write (from (40))

$$\int_0^\infty I(t)\epsilon^{-pt}dt = \omega EC \int_0^\infty \cos \omega t \epsilon^{-pt}dt + \frac{E}{R}\int_0^\infty \sin \omega t dt + \int_0^\infty I_a \epsilon^{-pt}dt. \tag{42}$$

This corresponds to

$$\frac{\omega A_1}{p^2 + \omega^2} + \frac{2\omega A_2}{p^2 + 4\omega^2} + \cdots + \frac{pB_1}{p^2 + \omega^2} + \frac{pB_2}{p^2 + \omega^2} + \cdots = \frac{\omega ECp}{p^2 + \omega^2} + \frac{E\omega}{R(p^2 + \omega^2)} + F(p). \tag{43}$$

Consequently

$$F(p) = \frac{pf(p)}{p^2 + \omega^2} = \sum_{k=1}^{k=n} \left[\frac{\omega k A_k}{p^2 + k^2\omega^2} + \frac{pB_k}{p^2 + \omega^2} \right] - \frac{\omega ECp}{p^2 + \omega^2} - \frac{E\omega}{R(p^2 + \omega^2)} \tag{44}$$

[8] *Transactions of the A.I.E.E.*, **51**, 1932, p. 392.

and

$$f(p) = \frac{p^2 + \omega^2}{p} \sum_{k=1}^{k=n} \left[\frac{\omega k A_k}{p^2 + k^2\omega^2} + \frac{pB_k}{p^2 + \omega^2} \right] - \omega EC - \frac{E\omega}{pR}. \quad (45)$$

On the other hand $f(p)$ is related to $\varphi(t)$ by the integral expression (7)

$$\int_0^\infty \varphi(\lambda)\epsilon^{-p\lambda}d\lambda = \frac{f(p)}{p}.$$

We can transform this expression by the means of Fourier's integral and consequently we shall have

$$\varphi(t) = \frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} \frac{f(p)}{p}\epsilon^{pt}dp.$$

This expression can be computed by any of the methods used by Heaviside, such as the Expansion Theorem or development in series.

In conclusion the author wishes to express his thanks to Professor W. F. G. Swann and to Professor J. B. Whitehead for their constructive criticism and suggestions.

FURTHER NOTES ON SAMPLING ANALYSIS, WITH APPLICATION TO COAL.

BY

M. C. HOLMES, Sc.D., AND RICHARD DOWNS,

West Virginia University, Morgantown, W. Va.

In a previous paper on sampling,[1] an equation was derived which gave the number of increments per sample required for a given accuracy. The equation was as follows:

$$n \geqq \frac{S^2}{x^2}\left[\operatorname{erf}^{-1}(y)\right]^2. \qquad (1)$$

In this equation, n is the required number of increments per sample; x is the allowed limit of tolerance, expressed as a fraction of the mean value $\bar{x}$; y represents the desired assurance of not exceeding that tolerance, expressed as a probability; and S is the coefficient of inhomogeneity of the material being sampled.[2] It is the purpose of this paper to take coal as an example, and to compare present methods of sampling with the implications contained in this equation, and to give the results of a certain experiment.

The A. S. T. M. Standards on Sampling Coal and Coke, dated September, 1934,[3] specify that "gross samples of the quantities designated herein must be taken whether the coal to be sampled consists of a few tons or several hundred tons, because of the following cardinal principles in sampling coal that must be recognized and understood; that is, the effect of the chance inclusion or exclusion of too many or too few pieces of slate or other impurities in what would otherwise

[1] Holmes, M. C., "Sampling Analysis and Sample Size," JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 219, No. 4 (April, 1935), p. 483.

[2] S is defined as $\sigma/\bar{x}$, where σ, the standard deviation, is given by the customary expression: $\sqrt{\frac{\Sigma(x-\bar{x})^2}{n}}$, $(x-\bar{x})$ representing deviations from the mean $\bar{x}$, and n the total number of such deviations.

[3] A.S.T.M. Standards on Coal and Coke, Committee D–5, September, 1934, p. 1.

have been a representative sample will cause the analysis to be in error accordingly, regardless of the tonnage sampled." This is put forth as the cardinal principle upon which all sampling should be based—that the same amount of coal must be taken for analysis regardless of the size of the lot being sampled. The authors of the present paper do not agree with this principle, but believe that a more *fundamental* principle operates, based upon the so-called Probability Law of Large Numbers, one result of which is that sampling errors vary inversely as the square root of the number of increments per sample. Therefore, the important consideration lies not in taking always the same size sample; but in securing the greatest possible number of increments per sample.

The acceptance of the principle of constant size of sample (1,000 pounds or more are recommended) leads to another difficulty and a further source of error. Since the 1,000 pound sample is too large for chemical analysis, it must be reduced in size. This is done in successive steps. A sample is taken from the 1,000 pound sample by halving; then from that by halving again; one from it by quartering; etc.—a sample from a sample seven times, with all errors multiplied thereby. Surely there must be cases in which the final sample is not at all representative of the original lot.[4] The entire process is not only time-consuming and expensive, but, what is more important, it is fundamentally wrong.

An idea which must be kept in mind is that *absolute certainty* concerning the properties of a given lot of coal is not attainable unless the entire lot is analyzed—which of course means destroying it in the process. So recourse must be had to sampling. Furthermore, it must be remembered that for any determination based on sampling processes there can exist merely a certain *probability* that the results are within given limits of the truth. Nothing more can be affirmed, and the sooner this is generally recognized and admitted, the more

[4] At places where considerable coal sampling is done, a mechanical crusher is generally used. Such machines crush the coal of the gross sample and automatically split and select a small portion for analysis. Morrow and Proctor ("Variables in Coal Sampling," Tech. Paper No. 645, Amer. Inst. Mining and Metallurgical Engineers, 1935) have shown that coal taken from the reject spout and from the sample spout of a mechanical crusher and splitter can vary as much as 1.0 for a 7 per cent. ash coal and as much as 4.0 for a 10 per cent. ash coal.

rapid will progress be made. Of course, this probability can be made as large as desired, and the limits as small as desired, by the proper choice of increment and sample size. A rational determination of increment and sample size therefore should rest on probability considerations. Equation (1) represents the results of such an attempt.

To illustrate the use of Equation (1), and to show how the results depend upon the orders of magnitude of the various quantities involved for the particular case of coal, the data given on page 11 of the paper by Morrow and Proctor [5] have been analyzed. The data show the results obtained when four different samples were taken from the same coal, each sample containing the same *number* of increments (100), but different sized increments.

Data from Morrow and Proctor.

Size of Pieces Number of Pieces	plus 6″ 100.	4″ × 6″ 100.	2″ × 4″ 100.	1″ × 2″ 100.	¼″ × 1″ 100.
Limits of % Ash.	Number of Pieces Between Each Limit.				
0 to 2.0	—	—	—	4	2
2 to 2.9	16	6	9	8	8
3.0 to 3.9	18	37	27	13	13
4.0 to 4.9	23	27	13	13	19
5.0 to 5.9	21	10	9	8	10
6.0 to 6.9	10	9	9	10	7
7.0 to 7.9	5	4	9	14	7
8.0 to 8.9	1	3	4	9	5
9.0 to 9.9	1	1	3	4	6
10.0 to 14.9	5	3	12	9	9
15.0 to 24.9	—	—	3	3	3
25.0 to 44.9	—	—	2	4	9
Over 45.0	—	—	—	1	2
Average % Ash, $\bar{x}$	4.9	4.7	6.7	8.0	9.3
Probable error, p.e.	1.25	1.11	2.94	3.81	5.54

Since the probable error, p.e., equals .6745 times the standard deviation, the coefficient of inhomogeneity, S, will be given by:

$$S = \frac{\text{p.e.}}{.6745\,\bar{x}}.$$

[5] Loc. cit.

This relationship permits the calculation of the following table:

Size of Increment.	Coefficient of Inhomogeneity, S.
plus 6″	.379
4″ × 6″	.352
2″ × 4″	.650
1″ × 2″	.705
½″ × 1″	.883

In Equation (1), the two parameters, x and y, are disposable; the third one, S, however, is not; it depends upon the nature of the material and the size of increment. Let us then give x and y the values .01 and .99, respectively, and see what Equation (1) tells about the number of increments required. In this case,

$$n \geqq \frac{[\text{erf}^{-1}(y)]^2}{x^2} S^2$$

$$\geqq \frac{[(2.58)]^2}{(.01)^2} S^2$$

$\geqq 66{,}600(.379)^2 = 9{,}560$ increments for the plus 6″ size.

Similarly there is obtained: $66{,}600(.352)^2 = 8{,}250$ for the 4″ × 6″ size; 28,100 for the 2″ × 4″ size; 33,100 for the 1″ × 2″ size, and 49,000 for the ½″ × 1″ size. One can next estimate the relative weights of the gross sample required for the five cases by assuming that the average weight of the pieces is proportional to the cube of the smaller dimension. The results are tabulated as follows:

Size of Increment.	Mean Wgt. per Increment lbs.	Number of Increments Required (n).	Gross Wgt. of Sample Required (nw) lbs.
plus 6″	9.98	9,560	95,500 (48 tons!)
4″ × 6″	2.95	8,250	24,300
2″ × 4″	.369	28,100	10,350
1″ × 2″	.0462	33,100	1,530
½″ × 1″	.00578	49,000	283

This shows in startling fashion the advantage of using smaller sized increments. *For the same accuracy*, the gross weights of sample required vary from 95,500 pounds for the larger sized increments to 283 pounds for the smaller size—a

ratio of 95,500/283 or 337 to 1. Thus, by using smaller sized increments, the same accuracy will be attained with less coal, less cost and less trouble.

In order to test the idea experimentally, the following experiment was performed:

Samples collected by two methods were simultaneously obtained on three kinds of coal as the coal was loaded into railway cars from the mine tipple. The kinds of coal sampled were modified mine-run coal; egg coal, $1\frac{1}{4}'' \times 4''$; and pea coal, $\frac{5}{8}'' \times 1\frac{1}{4}''$.

Method I is the large sample; accepted procedure recommended by the A. S. T. M. Standards was rigidly followed. The sample consisted of 1,000 pounds gross weight, and was collected by filling 100 pound sacks until 10 such sacks were obtained for each of the three kinds of coal. Shovelfuls were taken, in the case of the modified mine-run coal and the egg coal, at regular intervals from the conveyor-boom of the tipple. The pea coal was sampled by holding a shovel under the spout of the bin as the coal was falling from the bin into the car. The 1,000 pound gross samples were ground, and the gross sample reduced in accordance with the methods of the A. S. T. M. for coal analysis. Ash and sulfur determinations were then made on the three coals. In each of the three samples, the number of increments (shovelfuls) was approximately 40 to 50 per sample.

Sample Method II, for the small samples, was applied on the same coal by another sampler over the same interval of time during which the standard 1,000 pound samples were being taken. Method II consisted in obtaining a large number of small increments at regular intervals as the coal was loaded into the cars. Every possible precaution was observed to insure randomness in the selection of the small increment pieces; the sampler did not see the increment which his hand picked from the coal.

For the modified mine-run coal there were 214 increments in the sample which weighed 11 pounds, 7.5 ounces. Sixty-nine increments at minute intervals were taken from the screener side of the conveyor-boom. Seventy-three increment pieces were taken from the opposite side of the boom, away from the screener, at about minute intervals. Finally,

seventy-two increment pieces were obtained at random from the boom equidistant from its two sides. The sizes of the increment pieces ranged from fine coal, the size of a marble, to lumps as large as an egg.

The egg coal sample obtained by Method II consisted of 100 increment pieces, having a gross weight of 4 pounds, 6 ounces. The increments were taken in the following order: Thirty from the screener side of the boom; thirty from the opposite side of the boom; and forty from the center, equidistant from the sides of the boom. The pieces were chosen at random without the sampler looking at the boom as he picked the increment. The large sample obtained by Method I was taken at the same time from the same boom.

The pea coal sampled by Method II comprised 400 increments, having a gross weight of 4 pounds, 8 ounces. The increments for this sample were picked at the place where the stream of coal from the bin hit the coal in the car, and were so timed as to cover the period required to fill the car. It is doubtful if complete randomness of increment choice was attained in this particular case, because of segregation tendencies of the pea coal on streaming from the bin and on hitting the coal in the car.

The chemical analyses of the two sets of samples on the three coals were made in one laboratory by skilled coal analysts. The results for the pea size coal seem to indicate the segregation phenomenon which was not totally eliminated by the sampling methods. The modified mine-run coal, it is observed, shows the closest agreement.

The results are presented in the following table:

	Modified Mine Run.		Egg coal.		Pea coal.	
	Method I (Large Sample).	Method II (Small Sample).	Method I (Large Sample).	Method II (Small Sample).	Method I (Large Sample).	Method II (Small Sample).
Ash, Per cent.....	8.9	8.7	8.8	8.3	9.6	8.8
Sulfur, Per cent...	2.53	2.63	2.35	2.67	2.85	2.32

The experiment is to be considered merely as an exploratory, tentative attempt. The results, however, are quite

surprising. They show that the values obtained from the small, crudely selected, 11-pound and 4-pound samples check reasonably well with those from the large 1,000 pound samples. The probable errors of the large samples are not known exactly. In view of the results obtained by Morrow and Proctor,[6] however, it must be concluded that the two sets agree within experimental sampling error, and hence indicate the need for a reëxamination of existing methods of sampling coal for chemical analysis.

December 14, 1935.

[6] See Footnote 4, page 2 of this paper.

Electrically Cured Concrete for Grand Coulee Dam.—H. B. HODGINS. (*Electrical Journal*, Vol. 33, No. 4.) The schedule of placing concrete in the Grand Coulee Dam requires continuous operation throughout the year even though temperatures for considerable periods of time are well below freezing. The concrete is placed checkerboard style in forms having an average maximum size of 50 by 50 feet. The regulations of the U. S. Bureau of Reclamation allow a maximum depth of five feet to be placed in any block, followed by an initial setting of at least 72 hours. An unusual system of portable electric heaters and housings has been developed to maintain safe temperatures. Housings were made in units and placed over the concrete forms after they were poured. Each unit consisted of an arc-welded structural steel framework about 10 ft. square, on which was built a permanent wood roof. Under the eaves of this roof section are fastened large canvases or awnings that can be rolled up when not in use or when the unit is being moved. Within this structure, near the top, is the heating unit. When the housing is set on the form ready for use it resembles a tent. Air circulation is provided by a 24 inch fan. The heating unit itself consists of elements of standard edge-wound resistance tubes, commonly used for motor service. There is provided 20.2 kw. heating capacity per unit and the supply is three phase, 440 volts. In case of necessity circuit voltage can be raised to 460 by changing transformer taps, resulting in 22.2 kw. output from the heater. After a full season of hard use the system has given very good satisfaction.

R. H. O.

RESIDUAL MOISTURE IN CELLULOSE DIELECTRICS.

BY

E. W. GREENFIELD, Dr.Eng.,

Johns Hopkins University.*

The electrical behavior of insulating papers has been shown to be intimately related to the amount of moisture contained within the structure of such materials. Any rational study of the nature of the influence occasioned by occluded moisture is of necessity primarily interested in the process or processes by which moisture is taken up, as well as its amount and geometrical distribution within the composite paper structure. Knowledge of these factors at any particular condition of the paper may then enable prediction of the behavior of the insulation under electrical stress with fair degree of accuracy.

Fortunately the history of the study of cellulose and its derivatives is enriched by an amazing amount of research. Contributions by the most able workers in colloidal chemistry extend back for a period of almost fifty years, while contemporary literature is full of the development of the subject along the more modern physico-chemical ideas. From these sources it has been possible to develop the modern conception of the structure of cellulose and to interpret the imbibition processes on more or less rigorous lines. It is the purpose of this contribution to briefly call attention to the colloidal nature and structure of cellulose, the physical and chemical character of its typical adsorption and finally the behavior to electric stress which is expected to result from such a system exhibiting the properties described.

STRUCTURE OF CELLULOSE.

As is well known, chemical wood pulp paper made for the cable trade contains besides the principle cellulose ingredient, various solid impurities which either arise unavoidably in the beating and felting operations or are allowed to remain or are

* Now with the Research Laboratories, The Anaconda Wire & Cable Co., Hastings, N. Y.

purposely introduced to better certain mechanical properties. Resin and lignon impurities are of the latter type, whereas traces of inorganic salts and a residue of silica are more or less unavoidable. As compared with the cellulose and bound water, the volume of these impurities is probably negligible.

The actual composition of the paper structure is not known, but it appears to be principally an α cellulose with probably a small amount of oxy-cellulose and ligno-cellulose. Of the latter, the ligno-cellulose may be carried over from the woody state of the fiber but it is highly probable that the oxy-cellulose is formed from the pure cellulose by the action of light in the presence of atmospheric oxygen.[1] Large amounts of oxy-cellulose are very objectionable since it has a greater affinity for water than normal α cellulose and besides has marked chemical reducing properties. In connection with this it is well to note that exposure of normal cellulose to the action of ozone results in the formation of a type of cellulose peroxide.[2] In contact with moisture, hydrogen peroxide, mostly in nascent form, is slowly produced together with carbon dioxide and the cellulose peroxide decomposes to its aldehyde, oxy-cellulose. Or it may act as a catalytic agent conditioning the further oxidation. The dangers of such an acidic condition of cable paper fibers when impregnated by carefully refined oils can well be recognized.

The gross structure of high-grade Kraft paper may be looked upon principally as normal or α cellulose. Ultimate analysis of cellulose indicates the empirical formula $(C_6H_{10}O_5)$. Cellulose in its various forms is distinctly gel-like in character [3] and as such is definitely classified as a polyphase carbohydrate colloid, i.e. a system of dispersed solid units or micelles in a solvent phase. The gel may be likened to a mass of long intertwined fibrils, enmeshing solvent or dilute solution [4] as well as binding liquid of solvation, the filaments being composed of adhering particles. There is x-ray evidence that gelatination is in reality a crystallization process; i.e. many cottons have been shown to have decidedly crystalline structures.

The micelle of cellulose seems to be made of 40 to 60 parallel chains, each chain being from 50 to 80 hexosan units long. The chains constituting the fibrils are said to be held

together by secondary valence forces while the hexosan links of each chain are united by strong primary valence forces. By studies of X-ray diffraction patterns from cellulose samples there has been found [5, 6] the repetition of a so-called unit cell consisting of four ($C_6H_{10}O_5$) groups. Meyer and Mark give for the dimensions of this cell: width 8.35 Å., length 10.3 Å. (along fiber axis) and height 7.9 Å., and present a schematic atomic model for a micelle chain. Since in solutions the particles of cellulose present correspond in size to the micelles of the solid substance, we conclude that the cellulose micelle in any state maintains its unit chain individuality. This is important, since many differing kinds of cellulose in both the very dry state and moisture-saturated (23 per cent.) condition show identical X-ray diagrams, thus indicating that occluded water cannot be bound within the unit cells but exists as surface masses.

Cellulose belongs to that group of gels which are termed turgescible, that is, the imbibition of water is accompanied by a certain swelling of the fiber structure. Thus the celluloses are to be distinguished from the so-called non-turgescible gels, an example of which is silica gel.

"ABSORPTION" OF MOISTURE BY CELLULOSE.

It is to be expected from the nature of cellulose with its colloidal disperse structure that surface force phenomena should play an important role in relation to absorption of a liquid phase. A much used but nevertheless forceful illustration of the tremendous integrated surface that even the smallest volume of a colloid may contain, is to consider a unit cm. cube cut so as to produce unit mm. cubes.[3] This will result in 1000 little cubes having a combined area of 60 sq. cms. If we further reduce the cubes comparable in size to that of a cellulose micelle, say 10^{-6} cm. cubed, there will be produced a trillion cubelets having a total area of 6 million square cms. The interfacial area thus presented by the cellulose structure to a liquid surrounding or medium is seen to be extremely great as compared to its volume.

Now the surface free energy arising as a result of the unbalanced normal molecular forces at the interface is equal to the product of the surface tension and the area. Also from

the second law of thermodynamics we know that for equilibrium the total potential energy always tends towards a minimum. It is evident then that in a disperse colloid surface free energy can tend toward a minimum by reducing its area. For a solid disperse colloid like cellulose this may be evidenced by rounding of the micelles and a general tendency towards spherical units. In the case of fine droplets of liquids ($r \lesssim 10^{-4}$ cm.) in suspension, such as mist, there is a well known tendency for the smaller drops to vaporize and recondense on larger drops as a result of trend toward reducing surface energies; tiny droplets of mercury always coalesce into a single large drop. The only other way for the large surface energy to decrease is by decreasing the surface tension at the interfaces. For the case of pure liquids at a given temperature this cannot occur since the surface tension at the gas-liquid interface is fixed. However where the liquid contains a solute having the tendency to reduce the surface tension of the whole solution we do find a change in surface tension occurring. Since the decrease of surface tension of the solvent is a function of the concentration of the solute it is found that the surface of such a solution contains a greater concentration of the solute than the rest of the liquid. Conversely, where the solute raises the surface tension of a solution the surface interface contains a smaller concentration of the solute than the rest of the liquid. This theorem was first formulated by Willard Gibbs and is named after him. Such an increase or decrease in concentration taking place at a gas-liquid interface is termed an "adsorption," i.e. a loose (from the chemical standpoint) fixation of a substance at an interface.

Another type of adsorption occurs at a solid-liquid interface as a result of this tendency for the surface free energy to fall to a minimum. For most materials it is usual that the interfacial tension between liquid and solid is much less than the surface tension of the solid alone. Hence the liquid moves so as to become adsorbed or bound to the surface of the solid. When the liquid phase contains other substances in solution, that substance will be most strongly adsorbed which lowers the interfacial tension between liquid and solid by the greatest amount. The degree to which a liquid will spread over or wet

a solid is simply a question of how much the surface tension of the solid exceeds the sum of the liquid surface tension plus the solid-liquid interfacial tension. For non-spreading liquids the surface tension of the solid is smaller, so that the contact angle of the liquid is determined by the excess of the other two tensions and the action of gravity. In general the surface tension of the solid phase and the interfacial tension between liquid and solid are much larger than the surface tension of the liquid.[3] Hence the degree of wetting or of adsorption is largely dependent on the difference between the solid surface tension and interfacial tension. The real importance of surface tension value of the liquid lies in the fact that, although smaller itself, it controls the value of the larger interfacial tension between liquid and solid, viz. in general, the greater the liquid surface tension the lower the interfacial tension with accompanying increased adsorption of the liquid.

The adsorption of a liquid to a solid takes place with the evolution of heat. The theoretical basis for this is readily explained by noting that increased temperature would reduce adsorption, thus increasing the surface free energy, which is contrary to the law of minimum energy. Hence in the adsorption of liquids or vapors, a condensation is promoted and heat is liberated as a result. In a general way, then, it may be noted that in addition to a large disperse interfacial area, the factors which most promote the adsorption of liquids to solids are: high solid-air surface tensions, low interfacial tension, low vapor pressures (large condensability), low ambient temperatures and large heats of wetting. Another contributing feature which is operative in colloids of the porous nature of cellulose, charcoals, etc., is the fact that where the pores are small enough, the concave surfaces represented thereby have radii on the order of 10^{-5} cm. or less. The vapor pressure of liquids standing on such a concave surface is considerably smaller than on a plane surface so that the adsorbed films are strengthened as a result.

It seems highly probable from the foregoing that the interstitial system presented by cellulose, and in particular by paper, adsorbs water strongly. Where the cellulose is saturated with the liquid, containing 20 to 25 per cent., the pores are larger as a result of its turgescence and the bulk of

liquid may thus be contained unadsorbed in mass state filling the capillary passages.[8] The comparatively weak capillary forces holding this bulk liquid (weak because of the much reduced intersurface area) may be quickly overcome by desiccation or evaporation of any kind and the cellulose easily loses. As the cellulose proceeds to drier conditions the unadsorbed water is eliminated and a much smaller quantity is held in the adsorbed state as films or layers upon the micelle interfaces. The capillary pores also contract, so that where the adsorbed surface contains as many as 50 molecular layers the pore space is still fairly well filled. Using Langmuir's calculation [11] for the size of a water molecule, 3 Å., and taking the size of a paper capillary in the fairly dry condition, as $r = 10^{-5}$ cm., determined from a previous study by the author,[10] we estimate that about 1/3 the total pore cross-section is still taken up by adsorbed surface films of liquid.

In the condition above, the micelles of the cellulose become more or less separated from each other and form new interfaces with adsorption layers of liquid of varying thicknesses yet do not lose their essential cohesion.[12] Further loss of water can only be accomplished by subjecting the cellulose to conditions which decrease the adsorption forces. Now the amount of liquid adsorbed is governed by its adsorption isotherm. This is a quantitative equation first formulated by Freundlich for adsorption of gases by solids, which states the form of the variation of the amount adsorbed on the adsorbent as a function of the concentration of the adsorptive present. We have:

$$a = kC^{1/n},$$

where a is amount adsorbed,

C is the concentration of adsorptive,

K and n are constants.

It is noted that the adsorption isotherm equation yields straight lines when plotted on log-log coördinates. Study of the form of the actual adsorption isotherms for many materials shows agreement with the above equation; the quantity adsorbed per unit amount of adsorptive is very much greater at small concentrations than at large. For example, in the

adsorption by blood charcoal of acetic acid from aqueous solution, Freundlich finds the value of k to be 2.606 and that of $1/n$ to be approximately $1/2$. As will be shown later, the adsorption of water by cellulose paper has been shown by the author to yield an adsorption isotherm of the form of Freundlich's equation.

To return to the removal of adsorbed liquid in cellulose, the form of the adsorption isotherm indicates that the tendency of dry turgescible gel to take up water is so great that considerable pressure acting on the gel to keep it from swelling may be overcome. To illustrate, it is possible to split rocks apart by driving dry wood into a crevice and then soaking the wood with a little water. Conversely, high pressures are required to remove water from the gel and the pressure increases very rapidly as the adsorbed film is reduced in number of molecular layers. Freundlich [13] describes an instrument for measuring "turgidity pressures" and indicates that for very dry conditions, for example gelatin containing moisture and india rubber containing traces of various organic liquids, many thousands of atmospheres are required to squeeze more fluid out of the gel.

In drying of paper as accomplished in the cable research laboratory those factors (except mechanical squeezing) which operate to reduce the forces of adsorption are resorted to. The drying is carried out at high temperature and low vacuum pressure. Also at intervals for measurements, the vacuum is broken, dry air admitted and the sample then reëvacuated. This air wash serves to artificially increase the moisture vapor partial pressure which otherwise tends to attain a maximum value for a given unbroken evacuation process; in consequence, removal of adsorbed moisture is further enhanced.

There is little doubt that the last stages of such drying concern very thin films of adsorbed moisture approaching duo or mono molecular layers. A. Hochberg [15] studying the weight and conductivity of adsorbed moisture films in mica showed that, for air conditioned with pure sulfuric acid, the thickness of the adsorbed moisture film was about that of a single molecule. For vapor pressure near saturation, the adsorbed film on the mica reached a depth of 25 layers of molecules. Freundlich, in his "Kapillarchemie," describes

numerous desiccation experiments where the adsorbed films of liquid are reduced to the thickness of their single molecules. A few of the older investigators were of the opinion that the true adsorption film is almost always but a single molecular layer but the more modern researches have shown the adsorptive forces to extend out much farther from the interface. Under certain conditions, Tinker[9] believes the adsorption layers can reach a depth of 140 millimicrons.

ADSORBED MOISTURE IN "DRY" CABLE PAPER.

Recently, an investigation[14] on the dielectric behavior of cellulose paper was reported by the author in coöperation with Prof. J. B. Whitehead wherein, through a study of the progressive change in electrical response of the paper, it became possible, amongst other things, to make quantitative statements concerning the amounts of retained water. Figure 1 is reproduced here and shows the variation of the apparent capacity and power factor of the paper as the sample is subjected to lower and lower evacuation pressures. It is apparent that an equilibrium condition is reached at each evacuation pressure and that most of the decrease in power factor and capacity takes place during the first few hours of heating at atmospheric pressure, while subsequent decreases require considerably longer treatment under high vacuum. It has been shown that the observed decreases in power factor and capacity occur as a result of corresponding decreases in residual moisture as the sample proceeds in its drying treatment. Furthermore, the quantity of residual moisture at each evacuation pressure may be computed once its geometrical distribution within the paper is known. Both a minimum and maximum water distribution were computed and the average value taken as representative of the probable water content of the paper. Table I gives the results of these computations for each pressure of evacuation; incidentally the average values in column four have been checked fairly closely by a cable manufacturer using non-electrical methods.

Having the above data at hand it becomes pertinent to seek information concerning the thickness of the moisture films involved and the question of the kind of adsorption taking place. A rough computation of film thickness appears

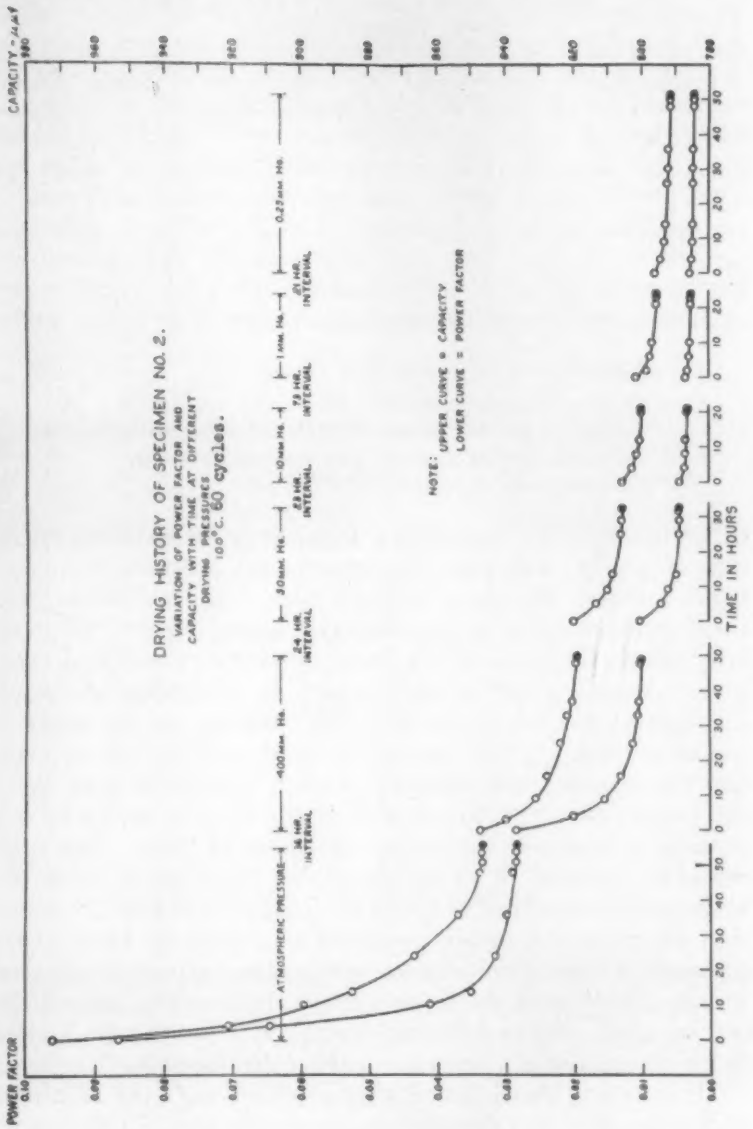

DRYING HISTORY OF SPECIMEN NO. 2.
VARIATION OF POWER FACTOR AND CAPACITY WITH TIME AT DIFFERENT DRYING PRESSURES
100°C. 60 cycles.
ATMOSPHERIC PRESSURE
16 HR. INTERVAL
400 mm Hg.
24 HR. INTERVAL
30 mm Hg.
48 HR. INTERVAL
10 mm Hg.
72 HR. INTERVAL
1 mm Hg.
81 HR. INTERVAL
0.29 mm Hg.
NOTE: UPPER CURVE = CAPACITY
LOWER CURVE = POWER FACTOR
POWER FACTOR
CAPACITY - μμF
TIME IN HOURS

TABLE I.
Calculated Moisture Content of Kraft Cable Paper.
Drying Temperature: 100° C.

Evac. Pressure mm. Hg.	Min. Moisture Content (% total volume).	Max. Moisture Content (% total volume).	Average Moisture Content (% total volume).
0.25	0.05	0.43	0.24
1.0	0.07	0.6	0.33
10.0	0.09	0.77	0.43
50.0	0.12	1.02	0.57
400.0	0.175	1.47	0.79
765.0	0.26	2.14	1.2

$$\text{Min. Moisture Content (per cent. total volume)} = \frac{K_\infty(C_\infty - C_0)}{C_\infty(K_w - 1)} \cdot 100,$$

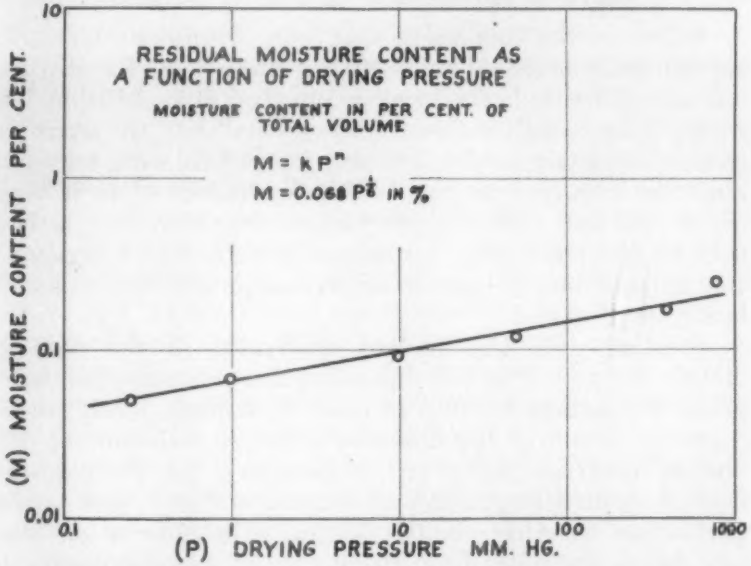
$$\text{Max. Moisture Content (per cent. total volume)} = \frac{K_w(C_\infty - C_0)}{C_0 K_\infty(K_w - 1)} \cdot 100,$$

K_w = Dielectric constant of water,
K_∞ = Geometric dielectric constant of paper containing residual water,
C_∞ = Geometric capacity of paper containing residual water,
C_0 = Geometric capacity of perfectly dry paper.

to be immediately available. For the most extreme condition of drying, 0.25 mm. Hg. evacuation pressure, the calculated average moisture content was 0.24 per cent. The total volume of the active dielectric being 154 cc., we arrive at a value of 0.37 cc. for the total quantity of occluded moisture. Assuming all of this water to be spread uniformly throughout the paper and knowing (from an earlier study on the same paper [10]) the average capillary radius, $r = 10^{-5}$ cm., and the approximate number of such capillaries making up the paper tape, 7×10^7, as well as the fiber to air ratio, it is possible to compute the surface thickness of film. This turns out to be about $2\frac{1}{2}$ Å., or a trifle smaller than the thickness of a single water molecule as given by Langmuir. For the condition at which the paper specimen was dried at atmospheric pressure, a similar calculation yields about 5 molecular layers for the thickness of the water films. Incidentally these calculations agree closely with those of F. W. Godsey, Jr.,[16] given in his discussion of the paper under consideration.

It appears, then, that drying of cellulose paper at atmospheric pressure and elevated temperature (100° C.) ultimately eliminates all bulk or unadsorbed water and an equilibrium prevails with the moisture distributed on the cellulose micelles

as adsorbed layers about 5 molecules in thickness. The further stages of drying under reduced pressure quickly decrease the amount and thickness of the adsorbed water film, but as the thinnest layers are approached the adsorptive forces are so great that even very low evacuation pressures have little effect. The results indicate that it is practically impossible to remove the mono-molecular adsorbed film without destroying the composite cellulose structure. The conclusion that the whole drying range between the evacuation pressures of 765 mm. Hg. and 0.25 mm. Hg. concerns itself entirely with the elimination of water existing as adsorbed layers is further borne out by Fig. 2, which is here



reproduced. This figure shows the relation, on log-log coördinates, between the evacuation pressure and the amount of moisture present in the paper sample at constant temperature. The curve indicated is a straight line which may be represented mathematically by

$$M = KP^{1/n},$$

where M is the amount of occluded moisture,

P is the evacuation pressure (P is also a function of the amount of water vapor)

K and n are constants.

As first pointed out by J. A. Duncan and R. N. Evans,[17] this experimentally derived relation is nothing but a Freundlich adsorption isotherm, and indicates that the controlling forces in the adsorption of water in cellulose are the same as for the adsorption of gases and other liquids by solids. Since the typical equation is obeyed over the whole evacuation pressure, we thus have further evidence of the existence of the water in the paper as adsorbed films. The values of "K" and "n" were deduced and these are: $K = 0.068$, $1/n = 1/6$. It is interesting to compare these values with those given by Freundlich for adsorption of acetic acid by charcoal previously.

ELECTRICAL PROPERTIES AT LIQUID-SOLID INTERFACE.

Based on the conclusion that "dry" cellulose dielectrics operate with occluded moisture distributed on the disperse internal structure in the form of adsorbed films, Murphy and Lowry [18] have analyzed with some particularity the contribution to dielectric conduction and loss which such a system might be expected to give. The importance of their work lies in the fact that the conclusions drawn by the authors may be directly applied to the case of cable paper insulation which has definitely been shown to contain adsorbed moisture in its "dry" state.

Starting with the modern conception of the cellulose micelle and the nature of the adsorption process which takes place, the authors develop an ionic mechanism which can account for much of the observed dielectric behavior of dry, fibrous materials under power frequency (as distinguished from very high frequency) alternating stress. Most important is that these ideas on the theoretical behavior of adsorbed ions follow naturally from the nature of the distribution of moisture and ions in an adsorbed state as elaborated by workers in colloid research.

Langmuir's [19] demonstration of the attraction for certain ions by the surface of a crystal has been applied to the case of colloid micelles to explain the preferential adsorption of electrolytic ions. Generally the micelle itself becomes electrically charged and is neutralized by an adsorbed atmosphere of contra-ions which may be of either sign.[20] The question of the number of ions adsorbed with relation to distance from

the interface has been investigated by Gouy,[21] Polyani,[22] Eucken [23] and others, while the potential required to tear off the adsorbed ions has been studied by Volmer and Estermann.[24] Correlation of these developments give Murphy and Lowry the basis for their theoretical extension to the dielectric behavior of hygroscopic materials.

The authors recognized that in addition to the forces between ions in solution there were larger forces between ions and the liquid-solid interface containing the electrolytic films or paths. Application of stress produces a polarized distribution of ions adsorbed in each layer of each cellulose structural unit. These ions undergo elastic displacements or reversible changes in distribution with the field and in consequence the composite dielectric absorbs energy. Extension of these considerations at once leads to rational qualitative explanations of relaxation time, dielectric absorption, conductivity-stress relations and other electrical phenomena occurring with hygroscopic dielectrics.

With the exception of Maxwell's inhomogeneity theory of dielectric absorption, the above adsorbed ion mechanism makes by far the strongest appeal to our reason in its simplicity and directness of application. The facts that well dried cable paper shows a regular decrease in dielectric absorption with decrease in moisture content and that the residual moisture appears to exist as adsorbed layers within the paper structure are strong evidence for the existence of a mechanism of the type outlined above.

In conclusion it should be emphasized that although a satisfactory theory may have its nucleus in the electrical behavior of an adsorbed moisture system, the ultimate problem is more extensive for the power cable engineer. For such service the dried paper must be impregnated with insulating liquids and the question of what happens when petroliferous saturants are introduced over the residual water, how it (the water) affects the impregnating process, its influence on resulting electrical properties, and, most important, on the life of the insulation, are problems which are yet to be undertaken.

July, 1935.

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CIVILIZATION SINCE JAMES WATT.*

BY

JULIAN P. BOYD,

Librarian and Editor, Historical Society of Pennsylvania.

The seed of any great idea or invention, if it is to germinate and come to full fruition, must fall upon fertile soil and be warmed by a sympathetic sun. Two thousand years ago, Hero of Alexandria invented a crude steam engine which he used to open and close the doors of the Temple. We do not celebrate him tonight because his amusing contrivance brought no far-reaching consequences and broke no chains binding humanity to age-old tradition and custom. But was this the fault of Hero? Professor Rostovtzeff, in his presidential address before the American Historical Association three weeks ago, expressed the opinion that the failure of Hellenistic civilization to reach the stage of modern society characterized by factory mass production and the use of complicated machinery could not be ascribed to the shortcomings of ancient science. In the world of Ptolemy and Euclid the "basic phenomena . . . which led to the construction of steam engines were well known to ancient specialists in mechanics." The plaything of Hero, therefore, failed to become an instrument of liberation because of forces over which the Greek mathematician had no control.

Other inventive minds such as Giovanni Branca, Edward Somerset, Savery, and Newcomen preceded Watt in reviving ancient knowledge of the steam engine, but again, the seed fell in unpropitious times.

We do not lessen the magnitude of Watt's contribution when we recognize that the success of his invention, like the failure of Hero's, was determined by forces outside of, and more powerful than, his ingenious mind. While we must admit the technical superiority of his device, we must also

* Address delivered at the dinner held under the auspices of The Franklin Institute on the occasion of the observance of the Two Hundredth Anniversary of the birth of James Watt, Tuesday, January 21, 1936.

recognize the fact that the birth of scientific inquiry in the age of Bacon and Descartes was a movement in part demanding, and in part being accelerated by, further invention and discovery. The Eighteenth Century was a Golden Age of inquiry and material change; research was subsidized by academies and learned societies. The work of MacLaurin, D'Alembert and Lagrange in advanced mathematics; of Bradley, La Place and Herschel in astronomy; of Du Fay, Galvani and our own Dr. Franklin in electro-physics; of Priestly, Scheele, and Lavoisier in chemistry, and, most important of all for James Watt, of Joseph Black in the problems of heat, gave impetus to change and improvement. Allied to this tremendous progress in science and giving sanction to it, was the idea of progress. When James Watt was still an infant, the Abbé de Saint-Pièrre published his "Observations on the Continual Progress of Universal Reason." Here was an idea so profound that an American historian has called it "the most dynamic social theory ever shaped in the history of thought, the idea of progress or the continual improvement in the lot of mankind on this earth by the attainment of knowledge and the subjugation of the material world to the requirement of human welfare." This concept of human progress, stretching out to an infinite future, was unknown to the thinking of Aristotle and Plato. Civilization, thought Saint-Pièrre, was in its infancy. Mankind could do more in one century to improve its status, he believed, than it had in two thousand years of complacent regard for the *status quo*. Saint-Pièrre looked forward to the time when international disputes would be settled by arbitration at the hands of a league of states; when the state would take over the education of its children; when highways and canals would liberate commerce from its earth-bound fetters. Swift and Fontenelle and others joined in the battle to free eighteenth century minds from the dead classical hand of the past, and to prepare the way for the future. Discontent with old methods became the norm of advanced thinking; the outlook was to the future, to a collective and purposive improvement in society, rather than to the past.

But all of the logic of the academicians, and all of the pamphleteering of the philosophers, could not compare in

effectiveness with the work of James Watt. The inevitable logic of the steam engine broke the age-old heritage of the past. The economic and social customs of centuries, by which man's power over his environment was limited to his material form and physical strength, were doomed.

In spite of the achievements of the sixteenth and seventeenth centuries in explorations and colonization, in the growth of commerce and capitalism, in the revival of natural and experimental science, in the emergence of the national state and in the appearance of a strong middle class engaged in industry and commerce—in spite of all this, life in England had changed little since the Middle Ages. An agricultural economy, dominated by a landed aristocracy secure in its control because of unequal political representation, still prevailed. Agricultural technique was similar to that in use for thousands of years. England in 1750 contained about seven million souls, and in many respects was so overcrowded that thousands of persons looked westward to America for greater economic opportunity. Material equipment was of the rudest sort, and chiefly of wood. Communication was slow and uncertain; in 1760, the king's subjects in America had to wait two months to learn of their sovereign's sudden death. Merchants bought and consigned goods without any sure knowledge of what the venture would bring. Roads were obstacles rather than aids to commerce. Mills were still dependent upon the caprice of wind and water. The majority of mankind were bound to a neighborhood, their outlook and knowledge of the world dependent upon the irregular and inadequate news that was conveyed by private courier, correspondence, and the weekly news sheet. A lone scientist in America like James Logan gained inspiration for his scholarly endeavors by correspondence with Peter Collinson, a man he never met. Few changes took place in such dominant social institutions as the family and the school.

Then came the steam engine, and the death-knell of the old system was sounded in the rhythmic beat of the walking-beam. Henry Adams, lost in adoration before the dynamo, saw the same mystic and inexplicable connection between the steam engine and that symbol of ultimate energy that he

saw between the Cross and the Cathedral at Chartres. Today, with our unprecedented material equipment in the form of telegraphs, telephones, newspapers, radios, airplanes, automobiles, concrete highways, subways and telephoto devices, we are conscious of the influence of James Watt on every aspect of our lives.

The steam engine meant freedom from the limitations of time and space. Great masses of people could gather in concentrated areas secure in the promise of food, shelter and clothing: London in 1936 could count an equal number with all those living in England in 1736. The factory system brought mass production and the inevitable change in family life. Industrial capitalism became paramount, molding laws and institutions in keeping with its needs. Science and engineering accelerated the growth of "the empire of the machine." With the increase in the numbers and power of the middle class came political democracy and the struggle for economic democracy. Provincial attitudes gave way to national attitudes, which were potentially more dangerous in proportion to their resemblance to provincialism. The resultant urban age brought strains to the nervous system of mankind, so long used to a simpler and more primitive life. Knowledge, taste, and custom became standardized under the machine technique, and men everywhere, though freed from the soil, felt themselves enslaved to the machine. The increase of commodity production and the growing interdependence of all parts of the world brought the quest for new markets and new sources of raw materials—the far-reaching movement of national imperialism.

Today four of the largest modern turbines have an energy capacity greater than that of the entire adult working population of the United States. Mankind appears to be on the eve of a third Industrial Revolution: first man did the work himself or used tools. Then came machines tended by men. Now we have machines watched and directed by other machines. How far this transference of intelligence to the machine has gone has been summarized by Stuart Chase: "The photo-electric cell, which never makes a mistake and never knows fatigue, has been introduced to sort vegetables, fruits and eggs, to measure illumination, appraise colors,

classify minerals, count bills and throw out counterfeits, time horse races, count people and vehicles, determine thickness of cloth, see through fog, record smoke in tunnels, inspect tin cans, substitute a new process for photoengraving, direct traffic automatically . . . count sheets of paper and measure their thickness, (and) automatically control trains—to name only a few of its uses." Automatic machinery for making electric light bulbs at Corning, New York, produces 650,000 lamps per machine per day—10,000 times that of methods previously employed. The implications of these facts for society in the future in the ever-present problem of technological employment are so obvious as to need no emphasis.

But, said Henry Adams, "All the steam in the world could not . . . build Chartres." That the past two centuries have witnessed phenomenal progress in material culture cannot be denied. But institutions, social customs and thought-patterns have, as always, lagged behind. Saint-Pièrre's idea of progress is beginning to be challenged, and such social pessimists as Oswald Spengler would substitute the notion of change for that of progress. To establish control over the gigantic material gains made and to cope with the resultant problems, are the challenges facing mankind today. Centuries, no doubt, will be required to answer these searching inquiries. But surely that intelligence which has performed well-nigh incredible feats in material matters will discover the avenue of social progress. If so, one of the guides to that avenue must be an understanding of the processes by which society came to be what it is. Perhaps the most important part of that understanding is recognition of the fact that the advanced thinking of one age, heralding a new order, sometimes becomes in a later age the argument for buttressing the existing order.*

*In preparing the above remarks, considerable use was made of Barnes, *History of Western Civilization* (1935) and Charles A. Beard's *Rise of American Civilization* (1927), as will be immediately apparent to anyone who has read these works.

The Needle Roller Bearing.—(*Engineering*, Vol. CXLI, No. 3665.) While the term "needle" in connection with the roller bearing is self explanatory, its adoption in machine design is so comparatively recent that some attempt to define it may be made. First, the length of the roller in this bearing is many times its diameter, some proportions adopted in practice being 2 mm. in diameter by 9.8 mm. long and 4 mm. in diameter by 37.8 mm. long. Second, the rollers in a needle bearing do not always run on special races, and are not spaced by cages or separators. Although the needle roller bearing is a post war development, it originated much earlier, for it would appear to have been used about 30 yrs. ago in some small mechanisms in which the rollers consisted either of the ordinary sewing or knitting needle, or were made from silver steel rods. Because of these materials there was strictly limited use. The modern bearing is capable of useful applications in many directions, its advantages being, generally speaking, most apparent in cases in which the diameter of the housing is restricted and light weight is important. Another field in which it is of special utility is with oscillating motions, e.g., in valve rocker arms, and certain mechanisms of printing and laundry machines. Applications of it should be considered on technical grounds only and because its cost is often higher, it should not be looked upon as an inexpensive substitute for the ordinary roller bearing. The needle roller bearing can be used at higher speeds as, owing to the small size of the rollers and the fact that the inner race is often formed by the shaft itself, the centrifugal forces are less.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

BROADCASTING OF MUSICAL STANDARD PITCH.

At the request of a number of musical organizations the Bureau has arranged a test radio broadcast of the musician's standard "A" tone of 440 cycles per second. The broadcast is intended for reception by musicians, musical instrument manufacturers, piano tuners, and others having need for an accurate standard of pitch. The standard "A" pitch will be broadcast on frequencies of 5,000, 10,000, and 15,000 kilocycles per second, simultaneously. The older broadcast radio receivers will not receive these frequencies, but most of the more recent ones and "short-wave" or "all-wave" receivers will. The standard pitch will be broadcast continuously day and night for two weeks (August 29 to September 12, inclusive) except from noon to 3:30 P.M. EST, on Tuesdays, Wednesdays, and Fridays, using a low-power transmitting set.

Depending upon the results of the two-weeks test, the Bureau may later arrange for regular broadcasting of the standard pitch. Persons desiring this service are requested to listen in during these tests and to write the Bureau, reporting on the reception and expressing their ideas on the usefulness of such broadcasts. More specific information about the test broadcasts may be obtained by writing to the radio section of the National Bureau of Standards, Washington, D. C.

PRECISION ATTAINABLE IN KNOCK RATING OF FUELS FOR INTERNAL COMBUSTION ENGINES.

The Bureau has completed an analysis of data obtained in coöperative knock ratings of fuels for internal combustion engines, to determine the normal experimental error and the factors affecting the precision of rating. The work was

* Communicated by the Director.

requested by the Coöperative Fuel Research Steering Committee.

This analysis is based on 2,180 tests of 99 fuels. For 1,882 tests made under the standard procedure, the probable error for the average of these fuels is 0.465 octane unit. The precision of rating is very nearly the same for straight-run gasolines, for blends of straight-run and cracked, and for leaded fuels of any base. The experimental error is distinctly larger for non-leaded cracked gasolines, and is still greater for benzol blends. Over the range of commercial fuels, the error of rating decreases with increasing octane number, being 0.5 unit at 55 octane number, and 0.4 unit at 75 octane number. From a consideration of the data, it appears that the probable error can be kept down to 1/4 octane unit with present equipment, if suitable precautions are observed.

Within the ranges covered by the tests analyzed, the result of a knock rating is not affected materially by ambient air temperature or barometric pressure, or dry-air pressure. The octane number obtained in a rating varies in some cases with humidity. The knock rating of sensitive fuels decreases as engine carbon increases. Variations in the intensity of knock used in testing contribute materially to the error of rating. From this analysis the indications are that the precision of knock ratings might be improved by the use of conditioned air and limitation of the period between engine overhauls to 50 hours, at least when testing sensitive fuels.

CARBON MONOXIDE INDICATORS FOR AIRCRAFT.

In coöperation with the National Advisory Committee for Aeronautics, the Bureau has modified some commercially available carbon monoxide indicators so as to make them more suitable for use in aircraft. These changes include an automatic regulator of the flow of the sample, remounting the parts so as to reduce the weight and size, and the substitution of an external source of suction, as a venturi tube, for the vacuum pump. An alarm has been developed which sounds when the carbon monoxide concentration exceeds 0.02 per cent. A method of testing has also been developed in which a standard sample of carbon monoxide is used.

The maximum amount of carbon monoxide in air to which a person may be exposed without harm for one hour is 0.04 per cent. at the ground level and falls off with altitude. Carbon monoxide in quantities dangerous to personnel may be present in the cockpits of airplanes or in the engine nacelles of airships. This may come about by a leak in an exhaust line, when the exhaust from the engine is used to heat a cabin or compartment, or be caused by the flow of exhaust gases into the cockpit of an airplane by an unforeseen condition of airflow. It is, therefore, highly desirable to have available a carbon monoxide indicator suitable for use in aircraft. In some cases a continuous indication is desired; in others merely a test to insure that the airflow about the aircraft is not such as to carry the engine exhaust into the cockpit or cabin. Both requirements have been met as a result of this work. A more complete account of the project will be found in Technical Note TN573 of the National Advisory Committee for Aeronautics.

SCOUR OF A SANDY RIVER BED BY CLEAR AND BY MUDDY WATER.

At the request of the U. S. Bureau of Reclamation an experimental study was made in the hydraulic laboratory of the National Bureau of Standards of the scour produced in a bed of fine sand in a sloping flume by muddy water, as compared to clear water. The experimental conditions simulated those existing in the Colorado River at the Boulder Dam before and after construction. It was found that, when the water contained an appreciable amount of clay in suspension, an increase of about ten per cent. in mean velocity of the water was necessary to scour out the same amount of Colorado sand as was scoured by clear water. For coarser sands this increase in velocity was greater.

Velocities characteristic of critical movement of the sand bed were found greater for muddy water than for clear water.

It was concluded that clear water discharged at the Boulder Dam will cause more scour of the river bed below the dam than the muddy water of the river before the dam was built.

The complete report of this investigation will be published as RP907 in the August number of the *Journal of Research.*

SOLUBLE DECOMPOSITION PRODUCTS IN AGED VEGETABLE-TANNED LEATHERS.

For the past few years the Bureau has studied the effect of sulphuric acid on leather. Leathers of different tannages and containing various leather making materials were treated and aged under different conditions. The deterioration in the presence of sulphuric acid was accompanied by the formation of soluble nitrogen compounds, among which were ammonia and compounds containing free amino nitrogen. As a means of studying the mechanism of deterioration and to obtain some data for an accelerated aging test, a study was made of the soluble nitrogen compounds in these leathers.

The results, as given in RP909 in the August number of the *Journal of Research*, indicate that most of the deterioration is caused by hydrolysis. The hydrolysis, however, is not complete since only small amounts of amino nitrogen are formed. The amount of ammonia present shows no relationship with the loss in tensile strength or the percentage of total soluble nitrogen.

LOAD DISTRIBUTION AND STRENGTH OF ELEVATOR CABLE EQUALIZERS.

Most elevator cars are supported by two or more wire ropes, and on their strength, the safety of the passengers largely depends. These supporting ropes are designed to carry a car with a liberal margin of safety, provided the load is equally distributed among them. Although the ropes are of equal length when installed and the load on each rope is adjusted (by means of threaded shackles) to be as nearly uniform as possible when new cables are put in service, these loads do not remain uniform except in a very few instances. All wire ropes stretch appreciably under load and in addition there is a gradual lengthening, which may continue for months or even years. For ropes of the usual construction, this stretch amounts to about one per cent. of the length of the rope under loadings ordinarily used in elevator practice. However, the stretch of two identical lengths of wire rope under equal loading will seldom be the same. This may be due to variations in the wires of which the strands are made,

to variations in the tightness of the lay, to variations in the core, or to other causes. In the case of elevator ropes, the distance between the crosshead of the car and the cable anchorage on the counterweight remains substantially the same, with the result that the tendency of the ropes to stretch different amounts results in unequal forces on the ropes.

Several companies have put on the market devices called elevator cable equalizers designed to remedy this condition. Such an equalizer is attached to the top of the car; the ropes being attached to the equalizer shackles. The shackles travel up and down as the cable lengths change, and the equalizer mechanism is designed so that, neglecting friction, it is in equilibrium only when the loads on the shackles, and hence the tensions in the cables, are all equal.

The effectiveness of various equalizers has been studied at the Bureau. Steel rods of adjustable length, representing the cables, were attached to the equalizer shackles and loaded in a testing machine. The distribution of load among the various rods was then measured for various degrees of inequality of rod lengths. The tension in each rod was calculated from the stretch of the rod as observed with Tuckerman optical strain gages.

RP912 in the August number of the *Journal of Research* gives the results of these tests, as well as those of tests made on the strength of the equalizers, the limits of travel of the shackles, and the effect of varying the total car weight on the equalizing characteristics.

COPPER WIRE TABLES.

The Bureau is glad to announce that in view of the continuing demand for Circular C31, Copper Wire Tables, it has been found possible to reprint this publication, which has not been available for several years. Copies may soon be purchased from the Government Printing Office. The price will be announced.

The tables in Circular C31 are in terms of the international standard values for the electrical resistivity, temperature coefficient, and density of copper, which were adopted in

1913 by the International Electrotechnical Commission and were based on research in the Bureau's laboratories. The history of the standard values is discussed.

Considerable attention is given to the subject of wire gages, including a brief history of their development, trend of practice at the time the Circular was prepared, and a detailed consideration of the American wire gage.

The tables are comprehensive and include, besides tables giving the relations of resistance, length, and mass for standard sizes, tables of standard resistivities and temperature coefficients, wire gages, cables, and aluminum wire. The data are duplicated in English and metric units.

Certain auxiliary questions, treated in appendices, include: (1) the expression of the various kinds of resistivity and units thereof; (2) calculation of the constant connecting the change of resistivity with the temperature, from the known law of proportionality between temperature coefficient and conductivity; (3) data on the density of copper; (4) calculation of the resistance and mass of cables; and (5) the international standard of resistance for copper.

YOUNG'S MODULUS OF ELASTICITY, STRENGTH, AND EXTENSIBILITY OF REFRACTORIES IN TENSION.

The brittleness of refractory products has in the past been a serious handicap to the study of their tensile properties. Within recent years the development of the optical strain gage for measuring minute length changes has given the research worker a tool which has eliminated most of the difficulties encountered in such a study, so that strain measurements of all types of refractory materials can be made with reasonable accuracy.

Although refractories are ordinarily subjected to comparatively small external loads, more information on their little known structural properties may lead to a better understanding of their behavior in certain types of service. A knowledge of the tensile properties of fired refractory products is desirable because of the trend toward the use of fairly large shapes in hanging roofs designed for modern high-power boiler settings, heat-treating, and other furnaces.

Also, there is often a decided lack of agreement in results of certain tests of apparently duplicate samples of refractory bricks or shapes.

A study was, therefore, undertaken at the Bureau to make available information on the tensile properties of the standard 9-inch size of firebrick, and also the extent of the variation in these properties within the brick and between bricks. This shape is produced in largest quantities, is readily obtainable, and enables a selection representative of the different localities and processes of manufacture, different degrees of heating, and different methods of setting in the kiln. The specimens used for study were machined from sections, the axes of which were initially lengthwise or crosswise to the brick.

A report has been released for publication giving information on the tensile properties of 16 brands of fire-clay brick, two of high alumina and one each of silica, chrome, forsterite, and mullite. The results of tests made on nine specimens (6 lengthwise and 3 crosswise of the brick) of three bricks of each brand show that the range in Young's modulus of elasticity was from 485,000 lb./in.^{2} to 5,255,000 lb./in.^{2}, the range in tensile strength from 115 lb./in.^{2} to 1,005 lb./in.^{2}, and the range in extensibility from 0.0120 to 0.0465 per cent. For dry-press bricks Young's modulus of elasticity of the crosswise specimens was greater than that of the lengthwise specimens; for stiff-mud extruded brick the modulus was less for the crosswise specimens than that for the lengthwise; and for the hand-made brick the moduli of elasticity of the crosswise and lengthwise specimens were nearly the same. The hand-made bricks showed more variation in properties from one brick to the next than either the dry-press or stiff-mud bricks. However, the range in maximum and minimum values for individual hand-made bricks was less than that for the other two types.

In general, bricks formed by the dry-press process had greater extensibilities than those formed by either the hand-made or stiff-mud process. The highly siliceous fire-clay brick and the silica brick, each having higher silica content than the other brands, and both made by the hand-made process, had higher extensibilities than any of the other brands.

Results of tests limited to one brand of dry-press bricks indicate that tensile properties of specimens cut from the bricks after firing are significantly affected by axial load during firing of the bricks in the kiln.

ACID RESISTANCE OF VITREOUS ENAMELS.

The acid resistance of vitreous or porcelain enamels has received increasing attention in recent years, and various tests have been used to determine the degree of resistance of different enamels. As a part of its general program of cooperation with the Porcelain Enamel Institute, the Bureau has been engaged in developing a test which will merit adoption as a standard.

The results of investigative work indicated that no satisfactory distinction could be made between enamels of varying acid resistance by determining the least concentration of a given acid which would cause visible attack under specified conditions, that is, the "threshold" concentration. Seven concentrations of citric acid were used, the strongest being 64 times the concentration of the weakest. Some enamels were not affected by any of the solutions, some were slightly affected by all, and those readily attacked were etched by even the weakest solution.

Another test method, namely, determining the degree of attack caused by a specified treatment with acid, gave promising results. For articles to be used at room temperature the treatment consisted of contact with 10 per cent. citric acid at room temperature for 15 minutes. For cooking utensils the treatment consisted of contact with a boiling solution of 2.5 per cent. malic acid for half an hour. Three degrees of attack could be distinguished visually:

(*a*) No visible attack.
(*b*) Attack visible, but insufficient to decrease ease of erasure of a pencil mark.
(*c*) Attack sufficient to prevent erasure of a pencil mark with a wet cloth.

While these three classes may be sufficient for commercial classification, research work requires the detection of numer-

ous degrees of acid resistance. For this purpose the loss of specular (mirror) reflection caused by the acid, as determined by a Hunter glossmeter, was taken as a criterion of the resistance. The following table illustrates the results obtained with specimens of a wide range of acid resistance.

Specimen.	Specular Reflection Index. Original[1] Value.	Specular Reflection Index. Percentage of Original After Treatment.
1	65	100
2	49	84
3	48	48
4	50	19
5	60	8

[1] Percentage × 10, thus an index value of 65 is equal to 6.5 per cent.

Metadyne Train Control Tried in London.—(*Transit Journal*, Vol. 80, No. 4.) Control of electric motors on the new rolling stock ordered by London Transport for the Hammersmith and City line will be of an entirely new type. Signor G. M. Pestarini, an Italian engineer, devised the system, known as "Metadyne" control. It was developed by the Metropolitan-Vikers Electrical Co., and this is the first trial on a multiple unit train in actual service. Instead of using a set of resistances in the motor circuit, in the new system the current passes to the negative rail through the metadyne, a type of rotary transformer driven by a regulator motor, and having the propulsion motors connected across the secondary brushes. Current induced in the secondary circuit drives the motors. By this system current is drawn sufficient only for the power requirements of the motors at any stage of acceleration. Rates of acceleration and retardation without slipping the wheels may be much greater than those possible on trains with the same number of motors and conventional control, as with the metadyne control acceleration is entirely without jerk, and there is a great smoothness in picking up speed. The standard type of train on the London railways has an accelleration rate of 1 to 1.3 m.p.h.p.s., whereas with the metadyne a rate of 1.7 can be attained, although there are more motored axles in the latter. For the new cars an accelleration of 2 m.p.h.p.s. is anticipated without discomfort to the passengers.

R. H. O.

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LIBRARY NOTES.

RECENT ADDITIONS.

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BOOK REVIEWS.

A TEXTBOOK OF PHYSICS FOR STUDENTS OF SCIENCE AND ENGINEERING, by Charles A. Culver, Professor of Physics in Carleton College. 816 pages, tables, illustrations, 14.5 × 22 cms. New York, The Macmillan Company, 1936. Price $4.00.

This book is an outgrowth of some thirty years of teaching and engineering experience and, the author states, the greater part of it has been used for several years in mimeographed form in his classes. The subject of physics has been a difficult hurdle for many students. It is a subject that cannot be minimized or presented in abstract form in order to facilitate understanding. However, it can be presented in an interesting light, a way not only to make the subject more easy, but to make it more impressive and applicable. With this as a fundamental thought, a book so constructed should be of much value. This book seems to follow these lines. The sequence of subject matter is logical and not without reason; references are made to historic matter to stimulate interest and to enable familiarity with the literature; the newer concepts of physics are introduced with those topics to which they naturally apply; the general tone is sympathetic to the needs of the student.

The content of the book is broad. Starting with treatments on force and motion it turns immediately to a clear treatment on vectors. Here is an illustration of logical sequence. Following this the text proceeds through work and energy, elasticity, fluids, liquids, to heat. Then gases are taken up and thermodynamics. The nature and general properties of light follow the physics of the atmosphere. The chapter on spectroscopy is especially well done. Electricity and magnetism, electronics, and radioactivity precede the treatment on sound which terminates the book.

The subject matter contains illustrations and formulæ not too complicated for the beginner. Problems to be solved as exercises are included. A knowledge of trigonometry is a prerequisite.

As a text it is excellent. For reference and review it can be highly recommended.

R. H. OPPERMANN.

AN ELEMENTARY SURVEY OF MODERN PHYSICS, by Gordon Ferrie Hull, Professor of Physics, Dartmouth College. 455 pages, tables, illustrations, 14.5 × 22 cms. New York, The Macmillan Company, 1936. Price $4.50.

This book is a clearly written text, intended, as the author states, for a second year course. "Emphasis is placed not on the computational or technical side but on the development of the atom idea, the methods of estimating dimensions and properties of atoms, of electrons; tentative proposals regarding the structure of the atom; a study of photons; a survey of a few of the vast number of interactions between matter and radiations." This is stated in the preface and an examination of the book bears it out. Because of the emphasis, the reader is able to get a long range and consequently broader practical view of the subject than otherwise, resulting in a more interesting exposition.

There are seventeen chapters to the book devoted to as many subjects.

Each chapter is treated in an elementary manner and while not avoiding mathematics entirely such passages are greatly simplified. An example of this is Chapter 3 on "Simple Properties of Orbits; The Discovery of the Nuclear Atom." Those familiar with this subject know that a great deal of the higher mathematics can be employed here, yet in this book the treatment is so simplified in this respect that only algebra is used.

Included in this elementary treatment other topics worthy of notice because of their complexity and what may have been cited as difficult in explanation heretofore are the Bohr theory and atomic spectra, the Zeeman and Raman effects, cosmic rays, and the uncertainty principle. In all these the experimental viewpoint is stressed. The text throughout contains references to the work of others in a way as to make it impressive and even spectacular in some instances. This book is no ordinary dry treatment. The chronological preview of modern physics in the introduction is a brief listing of events since 1895. The appendix contains a few mathematical derivations helpful to the advanced reader as he progresses through the book.

Undoubtedly this book will fit into a curriculum admirably. Aside from this it is a book for culture that should have much demand.

R. H. OPPERMANN.

CATHODE RAY OSCILLOGRAPHY, by J. T. MacGregor-Morris, M.I.E.E., and J. A. HENLEY, M.Sc. Monographs on Electrical Engineering, vol. 2. 249 pages, plates, 14 × 22.5 cms. Pittsburgh, Instruments Publishing Company, 1936. Price $6.00.

This is the second of a series of monographs on electrical engineering which satisfies a much felt need. The progress of electrical engineering is becoming so rapid that books of this nature are necessary in order that the practicing engineer has available a comprehensive treatise and one that is in compact form. The cathode ray oscillograph is now recognized as a measuring instrument invaluable in certain branches of electrical engineering. It is the result of outstanding work in pure physics and the understanding of the instrument must involve some knowledge of the properties of electrons. Literature on the subject is both comprehensive and voluminous; it is also scattered and thus available only by extensive literary search. This book therefore has a signal purpose.

There are eleven chapters progressing logically and covering the entire subject. The first or introductory begins with a treatment on the use of a stream of electrons produced by gaseous discharge. There follows electron beam theory, beam concentration and electron optics, hot and cold cathode oscillographs, their operation and limitations, applications, etc. Throughout this text the authors make every effort for clarity and completeness in method of presentation as well as the inclusion of drawings and photographs. The press work is exceptionally good.

Appended is a bibliography and a useful subject index.

The book has a definite place in the literature of electrical engineering. It will have exceptionally large use.

R. H. OPPERMANN.

A SYSTEMATIC HANDBOOK OF VOLUMETRIC ANALYSIS, by Francis Sutton, F.I.C., F.C.S. Revised by A. D. Mitchell, D.Sc., F.I.C. 631 pages, illustrations, 14 × 21.5 cms. Philadelphia, P. Blakiston's Son & Co., Inc., 1935. Price $10.00.

The twelfth edition of this 70-year-old standard has been for some time overdue since the last was issued in 1924. It comes out with a new pilot at the helm, Dr. A. D. Mitchell, who has perpetuated both the integrity of former editions and their useful character by some curtailment of older methods and judicious recognition of sound and promising newer techniques. The size of the volume has not been increased, more likely reflecting fixity of purpose on the part of the publishers rather than of the editor, with the wealth of material accumulated since 1924 at hand. The point of view is the British throughout, which calibrates glassware at 15° C.

A new section on potentiometric titrations has been concisely written by Dr. S. Glasstone and a considerably more extended discussion of the course of neutralization curves in terms of the pH convention has been added to the section on theory of indicators, both notable improvements. The discussions represent the minimum and readers should remember that a number of extended monographs are available on these subjects.

It should not be overlooked that this volume devotes nearly 100 pages to volumetric analysis of gases. The revisions found in this section are minor, the most notable being with reference to carbon monoxide. The section on micro-gas analysis refers to the determination of traces of gases in large volumes rather than the technique of handling very small quantities which the most common present usage of the term might suggest.

The reviewer has been frankly disappointed that in the new edition of this standard work the typography and art work have not been modernized, even to the extent of the conservative changes of scientific interest. Printed on paper of but fair quality, far off white, the book lacks the appeal of freshness desirable none the less for scientific works. If it shall attain something less than the full measure of popularity it should enjoy it may be on account both of this and the high price. The binding has been well done.

LESLIE R. BACON.

ACHEMA-JAHRBUCH, Jahrgang 1935–1936, Berichte über Stand und Entwicklung des Chemischen Apparatewesens. 258 pages, 15 × 21 cms. Berlin, Verlag Chemie.

Every chemical engineer and all those concerned with the manufacture and design of chemical apparatus will no doubt appreciate an opportunity to study carefully the latest edition of the German Society for Chemical Apparatus Yearbook. This particular volume is actually a complete survey of the equipment, machinery and apparatus exhibited at the Achema VII, Chemical Engineering Show, Cologne, 1934. Evidently the publishers appreciate fully the value of this Yearbook to foreign readers of like profession for they have supplied abstracts of each article in two languages other than the original. The three languages thus represented are German, French and English.

The contents have been arranged into three parts. The first part is quite

general and, in addition to the introduction, it speaks about the coming Achema VIII to be held at Frankfort-on-Main, July 2 to July 11, 1937.

Part Two is an alphabetically arranged classified index of the products exhibited at the Achema VII Show. The list is estimated to contain over 1,200 items.

Part Three consists of technical and industrial reports. In it the reader is told about new alloy steels of high specific resistance to various chemicals. Progress also is reported in the manufacture of resistant chemical plant apparatus from synthetic plastics. Among the new scientific apparatus may be found glassware of high resistance and of special form, also improved instruments that provide a convenient means of pH measurement. Among the scientific apparatus and processes for technical purposes will be found x-ray testing equipment, rotameter-type flow meters, high pressure and gas liquefaction apparatus.

Under processing equipment will be found a description of a mill combining grinding, air separation and drying. Mixing machines, proportioning pumps, acid resistant pumps and fittings, hydrochloric acid absorbers of fused silica, special filters, vacuum dryers, automatic filling and weighing machines, gas detectors and respirators, all share the "spot-light."

Naturally some of the space is occupied by advertisements which undoubtedly helped to make possible the attractive elaborateness of the 1935–36 Yearbook.

T. K. CLEVELAND.

THE THERMOCHEMISTRY OF THE CHEMICAL SUBSTANCES, by F. Russell Bichowsky and Frederick D. Rossini. 460 pages, tables, 15 × 23 cms. New York, Reinhold Publishing Corporation, 1936. Price $7.00.

The impressive subtitle "The Assembly of a Self Consistent Table of 'Best' Values for the Heats of Formation of the Chemical Substances (Except Carbon Compounds Containing More Than Two Carbon Atoms), Including Heats of Transition, Fusion, and Vaporization" at once explains the purpose and character of this volume. It comprises an introduction, tables of "best" values (154 pp.), text citing and discussing the original literature (236 pp.), a reference list of some 3600 citations, presumably to all sources of thermochemical data, and an index by elements alone to table and text.

This monumental survey will supplant the earlier tables by Bichowsky in I. C. T., which represented the first attempt to collate all published data involving heats of reaction. To the end that such a table be self consistent all original data require recalculation, the value selected must be the most accurate possible to obtain from known data, and finally it must be as consistent as possible with all known thermochemical data on reactions involving that substance. "It should be possible to obtain from this table, by simple addition or subtraction, the heat of any process involving any of the substances given, with an accuracy as great as is actually known."

It is noteworthy that the attempt made in I. C. T. to express heat changes in absolute joules is here abandoned (reluctantly) in favor of a *defined* calorie such that 1 calorie = 4.1850 absolute joules, which calorie bears no relation to the heat capacity of water except incidentally or historically.

This reviewer is not convinced of the net advantages of the arrangement of elements either as used in I. C. T. or in still different form by the present authors.

A system which leads to an order of listing such as PBr_5, $POBr_3$, PH_4Br, PI_2, PI_3, PH_4I, P_3N_5, $NH_4H_2PO_4$ is the surest way to discourage use. That this is so is most unfortunate since the valuable and accurate methods of thermochemistry are inadequately appreciated. Spectroscopic data, dissociation pressures, equilibrium data, vapor pressures, heats of solution, fusion, vaporization, sublimation, etc., temperature coefficients of solubility, E.M.F. data and the like have been prevailed upon for thermal computations. Conversely, thermal data may be frequently used in the opposite sense.

It may be pointed out that heat quantities for ions, and for atoms in excited states are frequently given, as well as electronic configuration data.

Beyond question an important job has been competently done, worthy of wide interest.

LESLIE R. BACON.

ELECTRONIC TELEVISION, by George H. Eckhardt. 162 pages, illustrations, 15 × 23 cms. Chicago, The Goodheart-Willcox Company, Inc., 1936, price $2.50.

Television. How many times have we heard this magic word as denoting another wonder of the modern age. Up to now, to the layman, the word has just meant "magic," for research along these lines has been carefully guarded. The technical man, however, has had opportunity to see in the literature, papers of a highly technical nature as evidence that research was being conducted along these lines and indicating the progress being made. This book is the first effort of publicity of this type on this new topic. It provides an opportunity for the general reader to understand what television is and how it works.

The author gives credit to Farnsworth Television Inc., and Radio Corporation of America as being pioneers in research which is about to give the public another scientific wonder. No less credit is given the radio amateur for his exploration of wave bands that at the time were of little use and who, upon development of these bands, had been forced into bands of shorter and shorter waves.

Electronic television is looked upon as a new art, an art calling for a new technic all around—new actors, new directors, new technical men—and everything else new. This book describing it is divided into three parts. The first is on the pickup and transmission of electronic pictures. Here fundamentals are discussed, the Farnsworth and R.C.A. system described, and the various methods for obtaining high definition are treated. The second part treats on the reception of electronic pictures, how it is done, with descriptions of the main parts of the two systems. The by-products of electronic research constitutes part three of the book. The first of these is the Farnsworth multipactor tube which takes advantage of the harnessing of secondary electron emission properties of metals and has many uses. Next, infra-red cameras for fog penetration and electron microscopes are described, and lastly an account is given of the R.C.A. three-meter radio circuit recently completed between New York and Philadelphia.

The book is well written, profusely illustrated, for the specific objective of the non-technical reader. The art of writing on highly technical subjects in a non-technical light is extremely difficult and the author is to be given credit for a great accomplishment.

If you wish a book that takes you through the halls of today's magic, explaining what man is now accomplishing, here it is.

R. H. OPPERMANN.

ASTRONOMY FOR THE LAYMAN, by Frank Reh. 308 pages, plates, 14 × 21 cms. New York, D. Appleton-Century Co., 1936. Price $3.00.

Poets from Aratos to Alfred Noyes have been inspired by the stars and Mr. Reh has performed a useful labor in gathering here in one volume more than four hundred quotations from their works. Well-known and often quoted excerpts from the *Phainomena* of Aratos; *Astronomicon*, of Manilius, and Noyes' *Watchers of the Sky*, are included, as well as others from lesser poets, or those whose astronomical interest is less familiar. It is surprising to see how accurate, in general, such references are, though of course there are errors, such as the famous slip made by Coleridge, when, in "The Rime of the Ancient Mariner," he sings of "The horned moon, with one bright star within the nether tip," or Longfellow's reference to Jupiter as "The mightiest star of all that shine, except the Sun alone!"

The author has tied these quotations together with a description of many of the features of astronomy of interest to the layman. More than a third of the book (112 out of the 291 pages of text) is devoted to the constellations. The myths connected with these groups are given, as well as some of the scientific facts that astronomers have learned about the objects in them. Another third (98 pages) is devoted to the Solar System, leaving only 81 pages in which to treat of the larger and most important features of the universe. The plan of the book doubtless makes this necessary, because of the scarcity of poetry concerning this part of astronomy.

It must be admitted, therefore, that this is not for the lay reader who wants a fairly complete and authoritative account of the science of astronomy as it stands today. However, several excellent books that answer this requirement have appeared during the past year, and "Astronomy for the Layman" may fill a different place. Perhaps it will appeal to the more romantically minded reader, and awaken in him an interest in the stars, after which he can turn to the other works, for more solid meat.

JAMES STOKLEY.

AN OUTLINE OF PROBABILITY AND ITS USES, by Maurice C. Holmes. 119 pages, illustrations, 13.5 × 21 cms. Ann Arbor, Edwards Brothers, Inc., 1936. Price $1.50.

To a great many engineers and scientists it is becoming more and more evident that probability is assuming increasing importance in technical lines. Its many and varied applications make it a powerful tool, the use of which reveals its true value. It should, therefore, constitute a part of the mental equipment of graduates of institutions of higher learning.

In this little book there is explained the probability theory in clear language. The objective meaning of the topic is treated on only. Most commonly used, the term is concerned with the strength of one's belief as to the truth or falsity of a proposition or of one's expectation as to the occurrence or nonoccurrence of some particular event. This is the subjective meaning of probability. The objective

meaning is connected with the observed uniformity of certain mass phenomena in nature, and with the strange regularity exhibited in the repeated occurrences of certain events which are supposed to depend entirely on chance.

After a brief introduction, fundamental operations are explained including permutations, combinations, compound and alternative probability. Then basic laws and concepts is gone into, the laws of large numbers and small probability, the normal probability curve, mathematical expectation and games of chance, and probability of causes. A large part of the book is devoted to applications of probability. Those who are somewhat familiar with the subject will find here many expositions of interest. Sampling processes and probable errors, the Lexian Theory, method of moments, etc. are discussed. A bibliography on the subject, an appendix containing useful constants, formulas and a set of tables is included.

The illustrative method of presentation,—treatment then problem solution—makes the text impressive upon the mind of the reader. The book should be valuable to all those desiring a practical working knowledge of the subject.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Thermochemistry of the Chemical Substances, by Russell Bichowsky and Frederick D. Rossini. 460 pages, tables, 15 × 23.5 cms. New York, Reinhold Publishing Company, 1936. Price $7.00.

An Introduction to Atomic Physics, by John Thomson, 228 pages, illustrations, 14 × 22.5 cms. New York, D. Van Nostrand Company, Inc. Price $3.50.

Anschauliche Quantentheorie Eine Einführung in die Moderne Auffassung der Quantenerscheinungen, von Dr. Pascual Jordan, 320 pages, illustrations, 16 × 24 cms. Berlin, Julius Springer, 1936. Price 12 R.M.

Carbon Dioxide, by Elton L. Quinn and Charles L. Jones. 294 pages, tables, illustrations, 15.5 × 23.5 cms. New York, Reinhold Publishing Corporation, 1936. Price $7.50.

Principles of Electric and Magnetic Measurements, Part I—Electricity, by P. Vigoureux. *Part II—Magnetism*, by C. E. Webb. 392 pages, illustrations, 15 × 23 cms. New York, Prentice-Hall, Inc., 1936. Price $5.00.

A Manual of Photo-Elasticity for Engineers, by L. N. G. Filon. 140 pages, illustrations, 13 × 19.5 cms. Cambridge, University Press, 1936. Price $1.50.

Simplified Structure Factor and Electron Density Formulæ for the 230 Space Groups of Mathematical Crystallography, by Kathleen Lonsdale. 181 pages, 22 × 29 cms. London, G. Bell & Sons, Ltd., 1936. Price 10 shillings.

Chrysler Corporation, Management Policies, Production Methods, Plant Services, Associated Activities, reprinted from the *American Machinist*, May 20, 1936, unpaged, 23 × 20 cms. Detroit, 1936.

Ebulliometry, by Wojciech Swietoslawski, 196 pages, tables, illustrations, 18 × 25.5 cms. Krakow, Jagellonian University Press, 1936.

Reichsverband der Automobilindustrie e. V., Schrittmacher der Wirtschaft, Vier Reden zur Internationalen Automobil- und Mottorrad-Austellung, Berlin, 1936. 32 pages, 16.5 × 24 cms.

Bell Telephone Laboratories, Monographs: B-929, A Study of the Electromagnetic Field in the Vicinity of a Radiator, by F. R. Stansel, 9 pages, tables. B-930, Neutralizing Transformer to Protect Power Station Communication, by E. E. George, R. K. Honaman, L. L. Lockrow, and E. L. Schwartz, 15 pages, illustrations. 2 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1936.

National Advisory Committee for Aeronautics, Technical Notes: No. 572 Performance of Air-Cooled Engine Cylinders Using Blower Cooling, by Oscar W. Schey and Herman H. Ellerbrock, Jr., 19 pages, illustrations. No. 573, Carbon-Monoxide Indicators for Aircraft, by S. H. J. Womack and J. B. Peterson, 9 pages, illustrations. B-574, Tank Tests of Models of Flying Boat Hulls Having Longitudinal Steps, by John M. Allison and Kenneth E. Ward, 13 pages, figures. B-575, Estimation of Moments of Inertia of Airplanes from Design Data, by H. W. Kirschbaum, 7 pages, illustrations. 4 pamphlets, 20 × 26 cms. Washington, Committee, 1936.

CURRENT TOPICS.

Crystal Gazing Put to Practical Use.—A bit of scientific crystal gazing whereby the garage mechanic can diagnose motor car ills as accurately as a doctor diagnoses human ailments was the subject of a paper presented by H. J. SCHRADER, of the RCA laboratories, during a meeting of the Institute of Radio Engineers. The heart of such a divining apparatus is a device which makes use of different crystals to detect different mechanical effects. Quartz crystals are employed to record pressure and Rochelle salts are used to measure vibration. The crystals are insensitive to sounds, which is of enormous advantage in tracing a vibration, to its true source. The tiny currents generated in the pick-up devices as a result of the effects they are measuring are connected to an oscillograph in combination with a new type of alternator. In the oscillograph an electron beam paints on a fluorescent screen a picture of what the crystal "feels," and in these visible wave-forms the automobile mechanic may read the nature of the trouble he seeks.

This new electrical equipment holds possibility of becoming a practical and highly useful tool in service stations throughout the country.

C.

Closed-Air System of Transmission.—(*Combustion*, Vol. 8, No. 1.) Transmission of power by compressed air has long been used to meet special conditions but, because of its relatively poor economy, it has been displaced by electricity wherever possible. A new "closed air" system introduced by O. E. Jorgensen and recently tested in a plant by G. & J. Weir of Glasgow is of interest. This system is described in the June issue of *Engineering and Boiler House Review* which says: "The essence of the matter is that when free air is compressed to about 100 lb. per sq. in. its rise in temperature of 360° F. represents power which is entirely wasted in most cases, but when air at 200 lb. pressure is further compressed to 300 lb. and used in a plant exhausting back to the compressor at 200 lb., the rise in temperature of about 55 degrees is relatively small and the power represented by the heat need not be altogether lost. In both cases the available effective pressure is the same, but there is clearly a large difference between the economy of the two methods. Furthermore, the compressor ratio in the first case is 7.8 but in the second

it is only 1.47 and this means a much smaller compressor for the closed-air system." Experiments to date indicate that an efficiency of 75 per cent. may be expected with this system.

R. H. O.

U. P. to Build First Steam Turbine Electric Locomotive.—(*Railway Age*, Vol. 101, No. 5.) The first steam turbine electric locomotive to operate on an American railroad will be constructed by the Union Pacific and the General Electric Co., this action being one of the first developments of the recently formed research department of the railroad. The locomotive will consist of two 2,500 hp. self-contained units, which can be operated individually or in synchronization and will be capable of a maximum speed of 110 m.p.h. with a trailing load of 1,000 tons. Delivery is expected early in 1937. The design of the locomotive is such that by operating both units it will be possible to maintain the schedules of limited trains in trans-continental service. The weight of the new locomotive will be approximately 20 per cent. less than that of a conventional steam locomotive, and lighter than the Diesel electric locomotives now used on Union Pacific streamliners. It will use fuel oil. Each of the units will be of the 4-6-6-4 type, the size of the wheels being 36 in.-45 in.-45 in.-36 in. respectively. The locomotive will have fuel and water capacity for a continuous operation for a minimum of 550 miles without refueling. The steam turbine of each unit will be connected directly to a 225 kilowatt, 3 phase, 60 cycle, 220 volt generator, which will provide electricity for the six traction motors, one of which will be mounted on the axle of each pair of the six driving wheels on each unit.

R. H. O.

Efficient Colored Light.—(*Power Plant Engineering*, Vol. XL, No. 8.) A new kind of lamp, developed in the research laboratories of the Westinghouse Lamp Co., changes invisible ultraviolet radiations into visible light of all the rainbow colors and from 50 to 120 times more plentiful than by present day methods. The phenomenon of fluorescence, by which invisible radiations of short wavelength are transformed into visible light, is the secret. Dr. R. D. Hall, Westinghouse engineer, explains, "A small globule of metallic mercury is vaporized by electricity until it fills a long, slender tube with a dull glow which is rich in ultraviolet radiations. Profuse ultraviolet radiations from this arc strike the inside surface of the tube where a coating of chemical powder transforms them into visible colored light, in a sense producing second-hand light. Knowing

how certain chemicals and minerals react to ultraviolet radiations, we can select the one to produce a desired color and use it as the powdered coating." The new lamps produce colored light at many times the efficiency of tungsten lamps. When consuming 15 watts they give more colored light than a 60 watt colored tungsten lamp of similar size. Research into this new method to date has been confined to the lumiline shape of bulb, the long, slender tube which is sealed at each end by a disc-like base. Engineers envision its use for decorative purposes when it finally emerges from the laboratory, probably being bent into various shapes. Producing light entirely by fluorescence, it is not to be confused with those generally classed as "neon."

R. H. O.

20,000,000 r.p.s.—(*General Electric Review*, Vol. 39, No. 7.) With the first ion receiving a 20,000,000-r.p.s. ride, the giant new atom-smashing apparatus of the University of Rochester will soon be officially placed in operation. Known in scientific circles as a magnetic resonance accelerator or, more commonly, a cyclotron, the new equipment has been under construction since September under the direction of Dr. L. A. DuBridge. One of a type invented by Prof. E. O. Lawrence, a physicist of the University of California, the Rochester cyclotron will be the second most powerful ever built. The windings of the huge magnet of the cyclotron, which contain five miles of copper strip and almost a mile of square copper tubing for water-cooling and which weigh nearly four tons, were built at the Pittsfield Works of General Electric Co. If the magnet were cut in two horizontally just under the exciting coil, the half-magnet produced would have a lifting power of a quarter of a million pounds. Assembly of the magnet has been completed at Rochester, but considerable time must be spent in completing the vacuum chamber, the high-frequency oscillator, and other subsidiary equipment, before operation of the cyclotron will be possible.

Shipped in Fresh Ice.—(*Business Week*, Aug. 8, 1936.) A. B. HASLACHER, of the Fresh-N-Ice Co., has made new developments in the technique of preservation of foods, a wet freezing process. Foods are sold frozen in 50 lb. blocks and in pint, quart, or gallon containers. Consumers merely thaw out the vegetables and cook them in the water from the melted ice, thus preserving their mineral salts. Placed in an ordinary mechanical refrigerator with temperatures ranging from 40° to 50° F., the product is said to keep fresh and palatable for from three to five days after thawing. Some

food industry authorities say the wet process of freezing is better than the quick, or dry, method, especially in the elimination of serious problems incident to dehydration and oxidation and in the ruggedness of the finished product in storage and transportation. Experience is said to have shown that an increase in weight due to the use of ice is more than offset by these advantages. Freezing is done in a "sharp" (low temperature) room or in brine tanks at 8° to 10° F. and because of this the process may be accomplished in any commercial ice plant where brine tank capacity is available. Processing includes preparation, grading, and blanching to inactivate the enzymes. The blanching fixes and heightens the color. Many different vegetables are so frozen and experiments are under way with freshly killed chickens.

R. H. O.

Large Quantities of Minerals Pass Through Bromine Plant.—(*Oil and Gas Jl.*, Vol. 35, No. 12.) During the two and one-half years of the operation of the bromine plant of the Ethyl-Dow Chemical Co. at Kure Beach, near Wilmington, N. C., one square mile of sea water, 172 feet deep, has been pumped in the process of producing bromine, of which the ocean harbors an inexhaustible supply. Present in this quantity of sea water were materials with a total tonnage of 5,699,335. Bromine recovered commercially totaled over 10,000 tons. Potential by-products not actually recovered from the sea water include sodium chloride, magnesium sulfate, calcium chloride, potassium chloride, magnesium, aluminum, strontium carbonate, iron, copper, iodine, silver, and gold. Besides these main constituents, practically every element and compound is dissolved in the ocean water to a greater or lesser extent. In extracting bromide from sea water, now an established industrial operation, chemical science has accomplished the initial conquest of nature's greatest reservoir of minerals.

R. H. O.

Designing the Longest Fixed Steel Arch.—D B. STEINMAN AND C. H. GRONQUIST. (*Engineering News Record*, Vol. 117, No. 7.) The main 800-ft. span of the Henry Hudson Bridge at present under construction over the mouth of the Harlem River, New York City, is the longest span fixed arch as well as the longest span plate girder arch built to date. It consists of two double girder arch ribs of silicon steel 12½ ft. deep and 50 ft. apart with a rise of 120 ft. which support a superstructure composed of spandrel

columns, continuous fascia girders, and a deck on a maximum grade of 2½ per cent. Steel towers, architecturally a dominant feature at either end of the arch span, are flanked by two 300-ft. continuous steel girder viaducts of 60-ft. spans, and concrete frame and wall approaches. The total length of steel is 1530 ft. and of the entire structure is 2000 ft. The structure's single deck will have a 42-ft. roadway and a 4-ft. sidewalk at an elevation of 160 ft. above high water. Comparative designs of two-hinged and hingeless arch types showed little, if any, difference in economy between them. The two-hinged arch, however, required the heaviest sections at the quarter point whereas the arch designed for fixed-end conditions provided ribs with a constant minimum section for three fourths of their length with a gradual increase in section toward the skewback for a distance of 100 ft. Because of greater stiffness of the fixed arch under live load and for other distinctly advantageous reasons, the fixed arch type was chosen.

R. H. O.

German Road Installs Unique Train.—(*Railway Age*, Vol. 101, No. 7.) The Luebeck-Buechere Railway has developed a two-unit articulated coach for use out of Hamburg. Not only does the coach present an interesting solution of the problem of reducing weight per passenger seat, but it also includes provisions for remote control of the streamline steam locomotive with which each coach is hauled so that the train does not require turning at the terminals. In one direction the coach is pulled by the locomotive and in the other is pushed by the locomotive at the rear end of the train. The first of these coaches was placed in service with a 2–4–2 type tank locomotive early in April. The coach has a total seating capacity of 300 in two decks. One unit is given over completely to third class with a small baggage compartment. There are seats in the two decks for 156 passengers. The other unit is divided between second and third class for which there are 144 seats. The car is 151 ft. 4½ in. long over the buffers with the spacing between the truck centers 64 ft. 8¼ in. It weighs 156,527 lb. and combined weight of locomotive and coach is 310,657 lb. Air conditioning is provided throughout the car and the windows are fitted with fixed sash. The electric remote control includes an electric motor and chain drive for the movement of the steam controls on the locomotive. This is arranged so that the control includes a "deadman" device, the compressed air cylinder for closing the throttle being operated simultaneously with the operation of the breaks when the deadman control functions. A loud speaker and bell device pro-

vides communication between the engineerman's station in the coach and the fireman in the locomotive. The train is designed to operate at a speed of 75 miles an hour.

R. H. O.

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